IceCube: Overview and Korean Contributions

Taeyun Kim on behalf of the Korean IceCube group

K-Neutrino Symposium 2026

Oct. 27, 2026 · Chung-Ang University

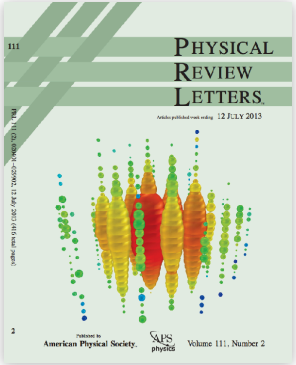


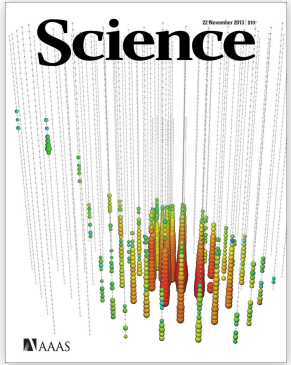
The 2026 Nobel Prize in Physics



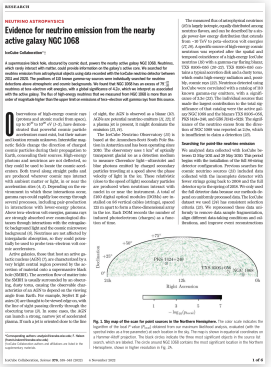
Royal Swedish Academy of Sciences, October 6, 2026 · photo: Althea Dotzour, UW-Madison

Discoveries: From a Diffuse Flux to Sources







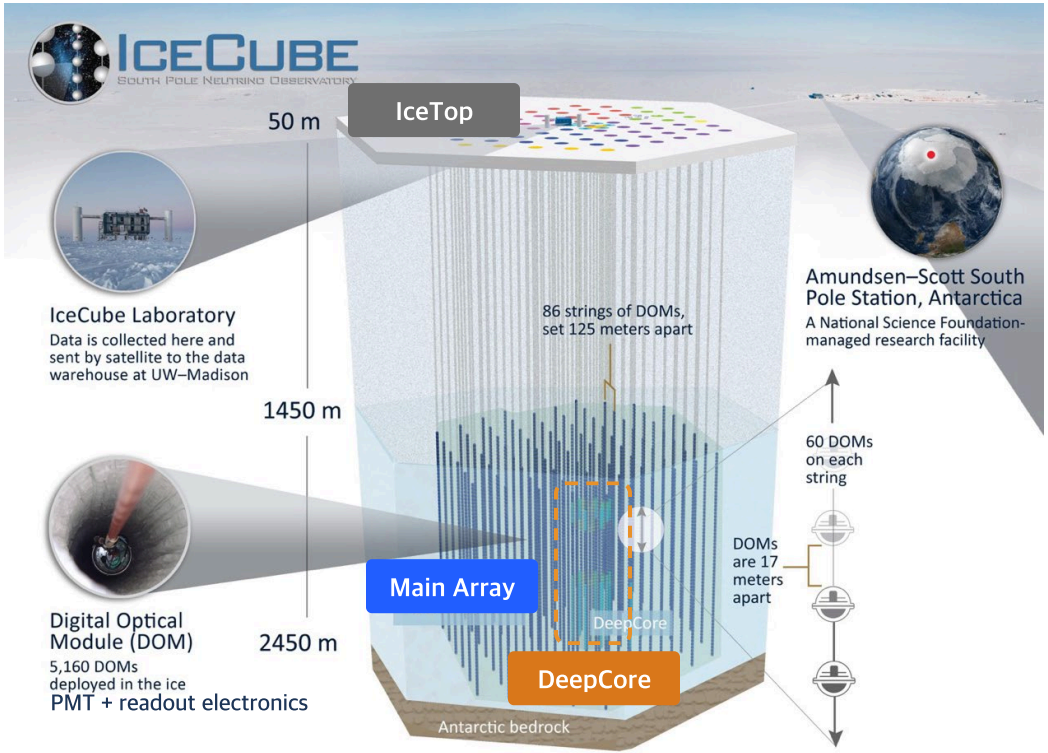


Nobel citation: "the discovery of high-energy neutrinos of astrophysical origin"

2013	**Detection of two PeV neutrino candidates** 2 events · 1.04 and 1.14 PeV · 2.8σ	PRL 111, 021103
2013	**Evidence for high-energy astrophysical neutrinos** 28 events · 2 years · 4σ	Science 342, 1242856
2014	**Observation of high-energy astrophysical neutrinos** 37 events · 3 years · 5.7σ	PRL 113, 101101
2018	**Evidence for neutrino emission from TXS 0506+056** 2014-15 archival flare · 3.5σ	Science 361, 147
2022	**Evidence for neutrino emission from NGC 1068** excess of ~79 neutrinos · 2011-2020 · 4.2σ	Science 378, 538
2023	**Observation of neutrino emission from the Galactic plane** cascades · 10 years · 4.5σ	Science 380, 1338
2026	**Galactic-plane neutrino emission established at 5.7σ** 12 years · combined event types	arXiv:2607.25966

Science 361 cover credit: Science; Jamie Yang and Savannah Guthrie, IceCube/NSF

The IceCube Detector



1 km³
Instrumented Antarctic ice

5,160
In-ice Digital Optical Modules

86
Vertical strings, including DeepCore

1,450–2,450 m
Depth below the surface

Main Array
~125 m string spacing for high-energy neutrino detection

DeepCore
Dense inner array for GeV atmospheric neutrinos and oscillation studies

IceTop
Surface array for cosmic-ray air showers

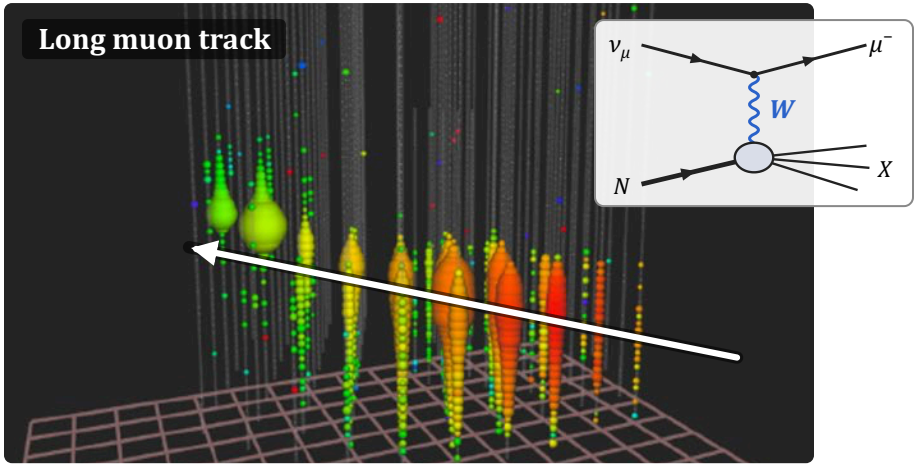
Numbers exclude the IceCube Upgrade

Figure: IceCube · Nobel Scientific Background (2026); IceCube, Astropart. Phys. 35 (2012) 615; PRL 120 (2018) 071801; NIM A 700 (2013) 188

Neutrino Detection in IceCube

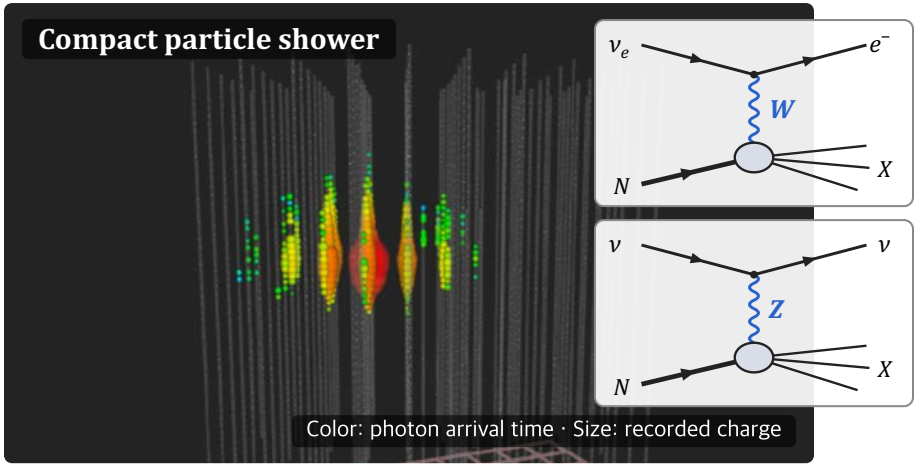
Track $\nu_\mu + N \to \mu^- + X$ [CC]

N: nucleon · X: hadronic final state



- **Good angular resolution:** ~0.3° at 100 TeV
- **Limited energy resolution:** muon energy within a factor of ~2

Cascade $\nu_e + N \to e^- + X$ [CC] $\nu + N \to \nu + X$ [NC]



- **Good energy resolution:** ~8% at 100 TeV
- **Limited angular resolution:** ~5° above 50 TeV

Reconstruction

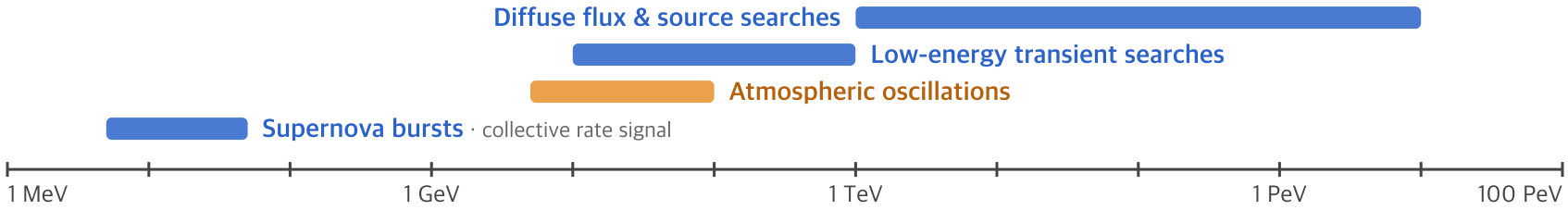
- **Direction:** infer track or shower direction from photon arrival times and the spatial hit pattern
- **Energy:** estimate deposited energy from the light yield; infer muon energy from its energy-loss profile

Requires accurate models of light propagation in ice and sensor response

Event displays and resolutions: IceCube, Nobel Scientific Background (2026) · IceCube, ApJ 995 (2025) 11

IceCube Science

Probing cosmic sources and neutrino properties



Neutrino Astrophysics

- **Neutrino sources and multi-messenger astrophysics**
- Diffuse flux, spectrum and flavor
- Low-energy transients and supernova bursts

Neutrino Physics

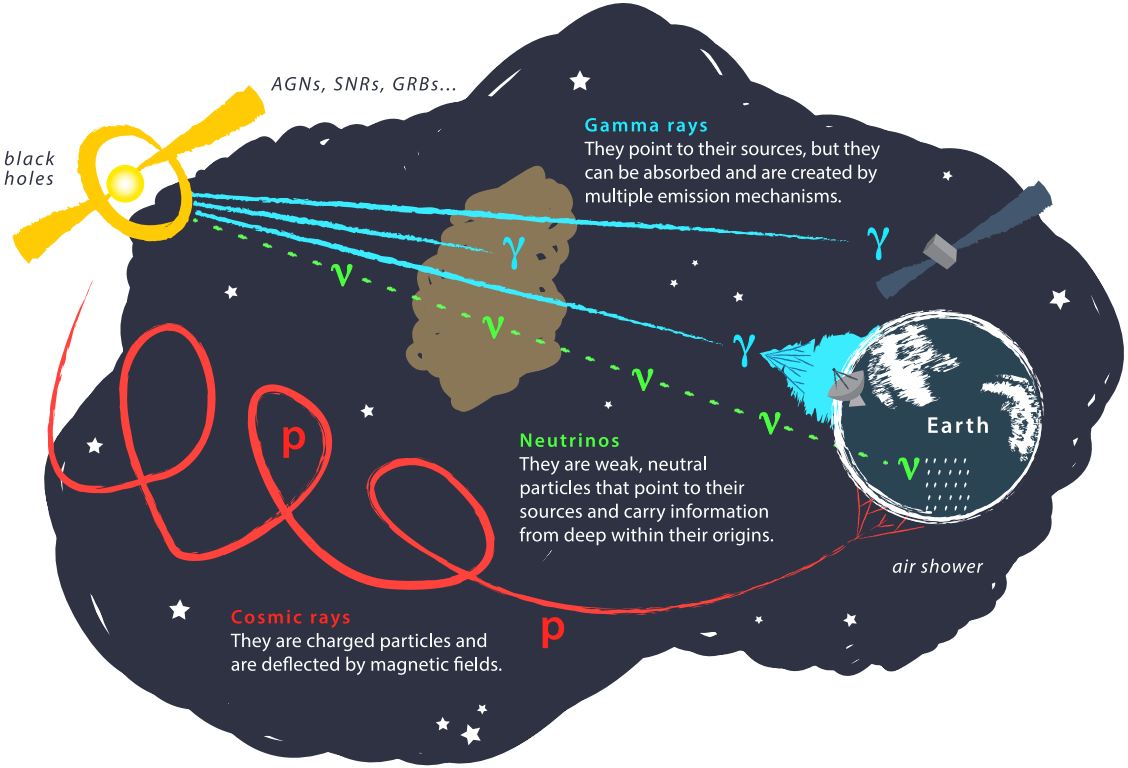
- **Neutrino oscillations and mixing**
- Flavor appearance and disappearance
- Sterile neutrinos and non-standard interactions

Other Topics

- Cosmic rays with IceTop
- Dark matter and physics beyond the Standard Model
- Earth and atmospheric science

IceCube, arXiv:1108.0171; ApJ 964 (2024) 126; arXiv:2405.02163; PRL 136 (2026) 121002

Neutrino Astronomy



Pointing Back to Sources

No magnetic deflection — electrically neutral

Weak interactions — little scattering during propagation

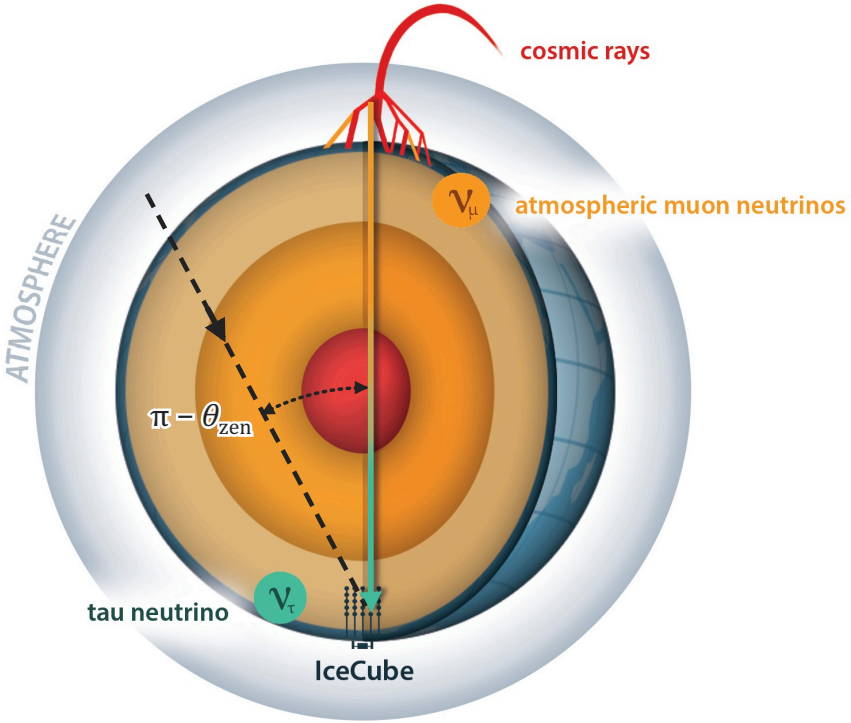
Tracing Hadronic Interactions

Probe cosmic-ray interactions with matter or radiation, including in environments opaque to gamma rays

Neutrinos reveal where cosmic rays interact and help identify their accelerators

Figure: IceCube · Nobel Scientific Background (2026)

Neutrino Oscillations with DeepCore



Atmospheric Neutrinos as a Natural Beam

A wide range of energies and Earth-crossing baselines

Measuring Neutrino Oscillations

Identify flavor changes through energy, zenith and event topology

Precision Oscillation Measurements

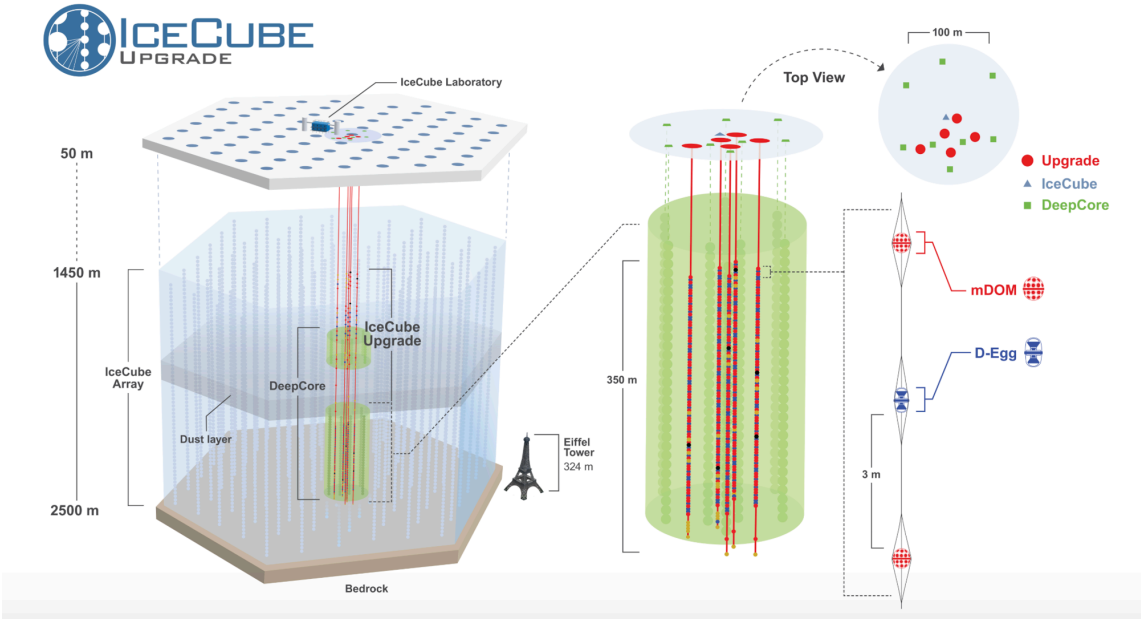
Constrain θ_{23} and $\Delta m^2{}_{32}$

DeepCore complements accelerator experiments by measuring neutrino oscillations at higher energies and longer baselines

Figure: IceCube Collaboration (2019), adapted · IceCube, arXiv:2405.02163

The IceCube Upgrade: Current Status

A dense detector infill within DeepCore, deployed in 2025/26





mDOM 24 PMTs



D-Egg 2 PMTs

5
New strings installed

505
New optical modules

~20 m
Average string spacing

3 m
Vertical module spacing

New calibration devices
Light sources, cameras and acoustic modules
Improved ice and detector models will benefit both new and archival data

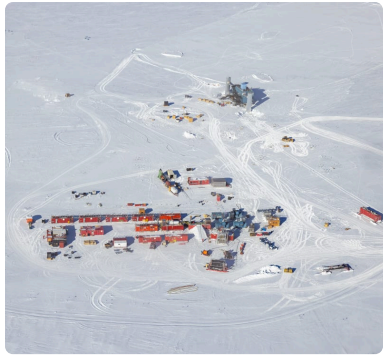
Status — September 2026 Commissioning underway; joint science data taking with IceCube expected in fall 2026

A. Eimer for IceCube, arXiv:2609.24387 (2026)

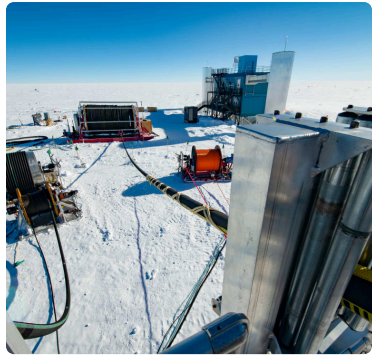
Upgrade Deployment, 2025/26



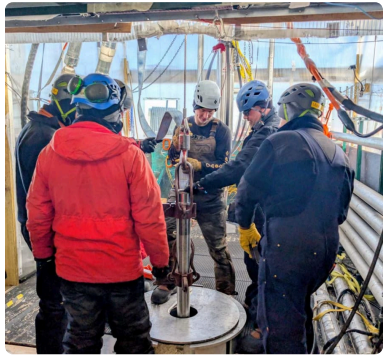
Lowering an mDOM



The Upgrade drill camp



Drill site and IceCube Lab



Module deployment at the borehole

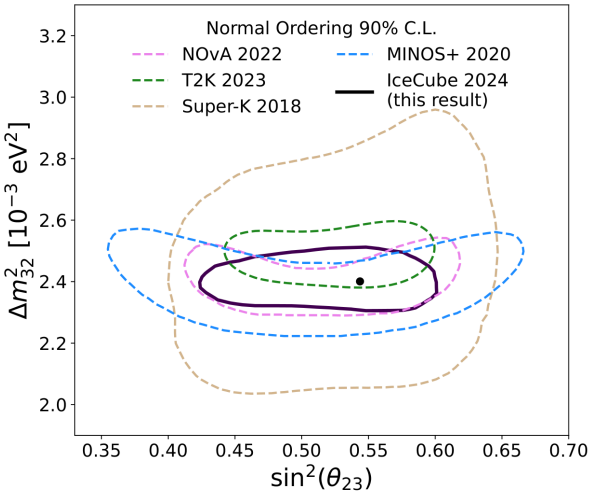


The Upgrade deployment team

The Upgrade: Precision Oscillation Measurements

DeepCore measurement

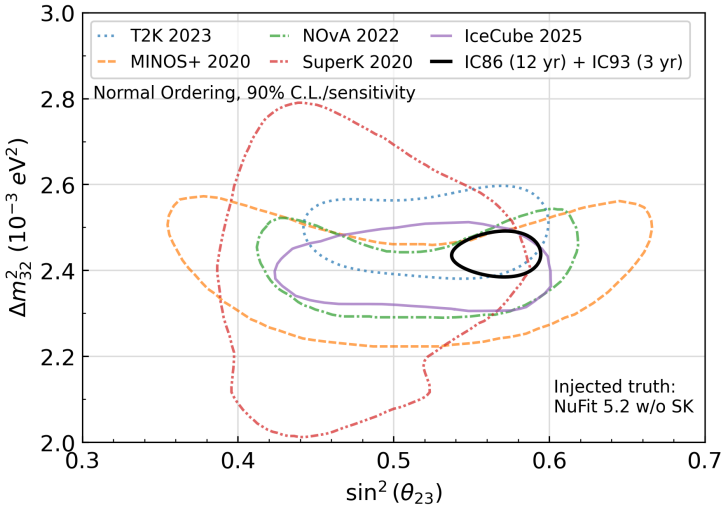
9.3 years of DeepCore data
Normal ordering · 90% C.L. contour



Best fit ± 1σ: $\sin^2\theta_{23} = 0.54^{+0.04}_{-0.03}$, $\Delta m^2{}_{32} = 2.40^{+0.05}_{-0.04} \times 10^{-3}$ eV^2

DeepCore + Upgrade projection

12 years of IceCube + 3 years with the Upgrade
Normal ordering · 90% C.L. sensitivity · 7-string design



Injected truth (NuFIT 5.2 w/o SK): $\sin^2\theta_{23} = 0.572$, $\Delta m^2{}_{32} = 2.437 \times 10^{-3}$ eV^2

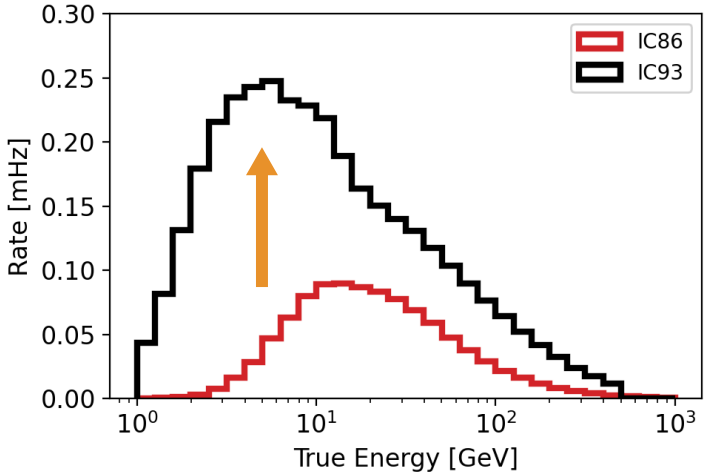
The Upgrade will improve precision on $\sin^2\theta_{23}$ and $\Delta m^2{}_{32}$

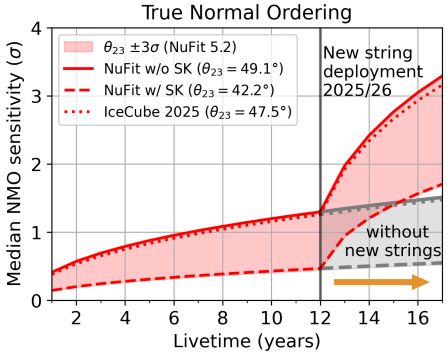
IceCube, PRL 134 (2025) 091801, Fig. 5 · IceCube, PRD 113 (2026) 072009, Fig. 11(a)

The Upgrade: More Events, Greater Sensitivity

More low-energy neutrino events

Simulated selected-event rates: IC86 baseline vs. 7-string Upgrade design (IC93)

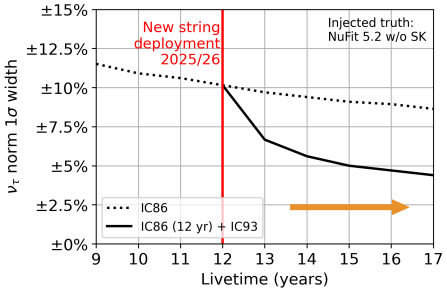




Neutrino mass ordering

Up to ~3σ with 5 years of Upgrade data

True normal ordering; θ_{23} in the upper octant
7-string design



Tau-neutrino appearance

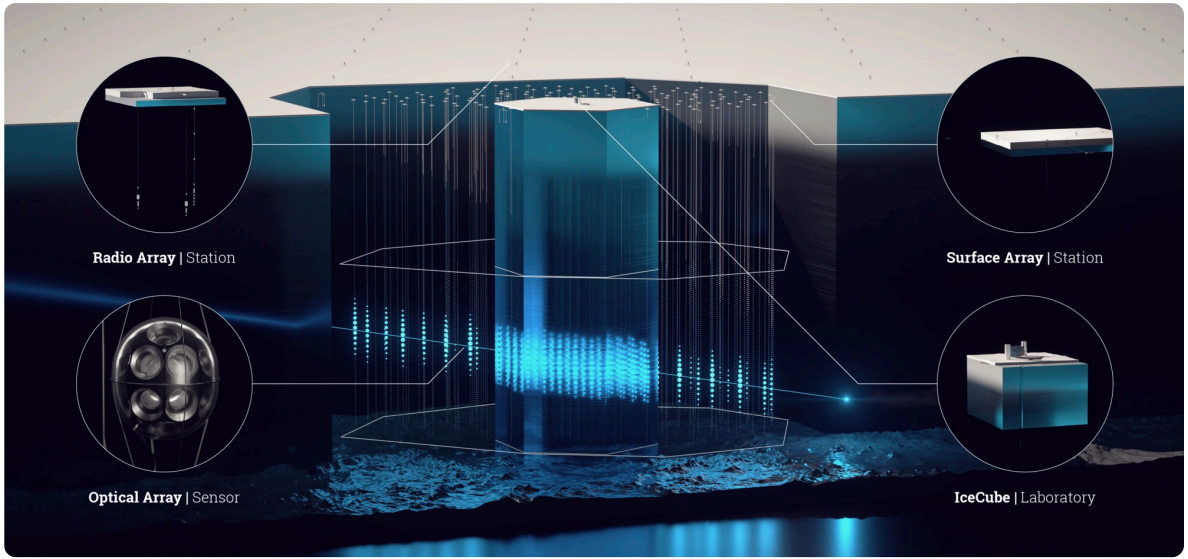
~5% uncertainty on ν_τ normalization with 3 years of Upgrade data

1σ uncertainty · 7-string design

More low-energy events and better reconstruction expand oscillation measurements

IceCube, PRD 113 (2026) 072009, Figs. 8, 13(a), 12(b) (simulation and projections)

IceCube-Gen2: Design and Science Goals



8 km³
planned optical volume

~5× fainter
neutrino sources in the published design forecast

TeV–EeV
combined optical and radio reach

Science Goals

Resolve more sources

A larger optical array collects more astrophysical neutrinos

Reach higher energies

A radio array extends the search to the highest-energy neutrinos

Connect the messengers

The surface array measures cosmic-ray air showers and provides a veto

IceCube-Gen2, J. Phys. G 48 (2021) 060501; Technical Design Report (2023-24)

The IceCube Collaboration




Collaboration meeting, Madison, Fall 2026

~450 people

58 institutions

14 countries

Korea Chung-Ang University Sungkyunkwan University

The Korean IceCube Group

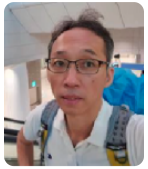


K-IceCube Workshop, Feb. 2026

Chung-Ang University

Low-energy / particle physics

Atmospheric neutrinos and oscillations, Upgrade reconstruction, and event selection



Chang Hyon Ha
Institutional lead



Hani Kimku
Student



Minsu Kwak
Student



Sooa Kim
Student

Sungkyunkwan University

High-energy / multi-messenger astrophysics

Neutrino source searches, reconstruction, and calibration



Chang Dong Rho
Institutional lead



Youngwan Son
Postdoc



Taeyun Kim
Student

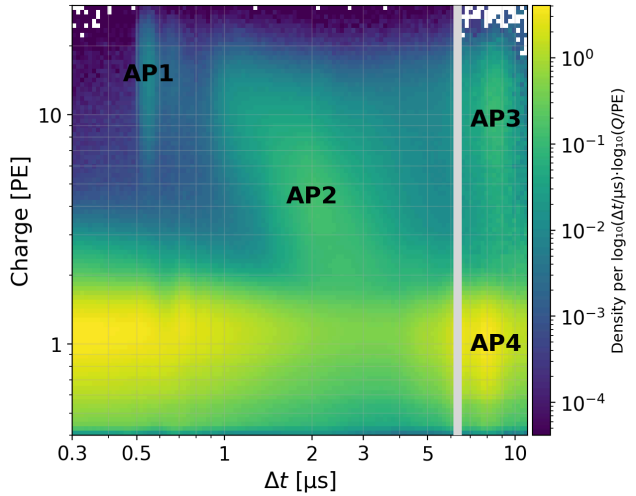


Minji Shin
Student

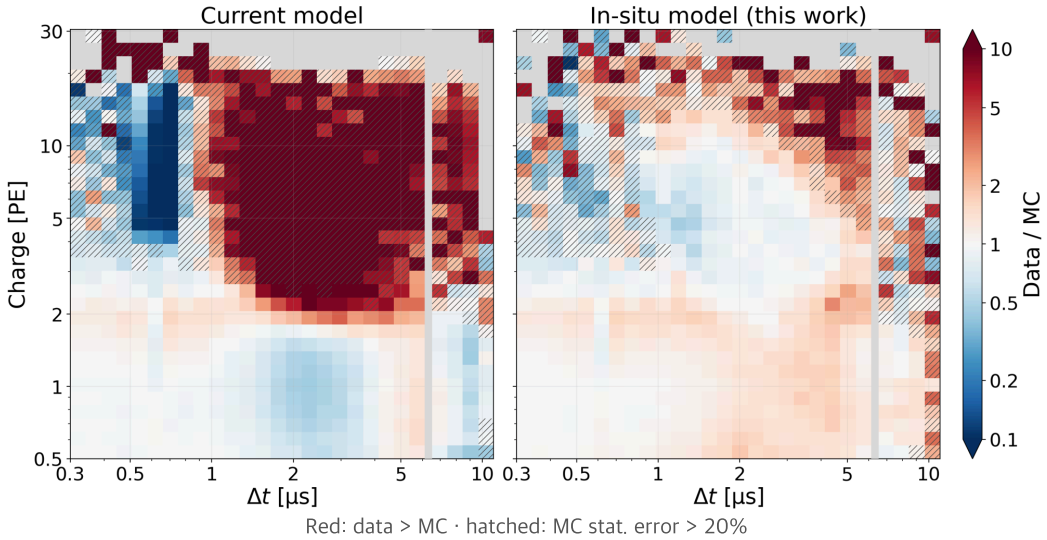
In-Situ Measurement and Modeling of PMT Afterpulses

Taeyun Kim (SKKU)

In-situ IceCube data



Data / MC with each afterpulse model in IceCube simulation



Afterpulses measured in situ using all in-ice DOMs give a new simulation model, much closer to data than the current lab-based model

Gupta-Track Reconstruction with a Noise Model

Minji Shin (SKKU) with Rishi Babu, Mehr Un Nisa (MSU) and Matti Jansson (UCLouvain)

Gupta-Track reconstruction

What a neural network predicts when a muon's light reaches each DOM

Before Pandel: one analytic shape; SplineMPE: photon tables

Gain timing set by the track geometry and the layered ice; aims to be accurate and fast

muon track guess

↓

Neural network
when does light reach each DOM?

↓

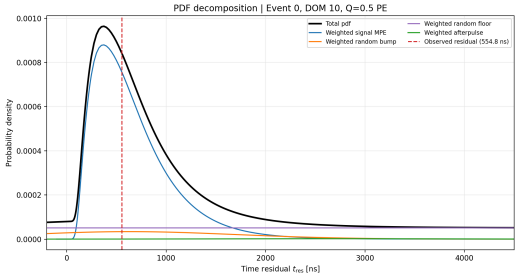
match the hits → best track

Noise model

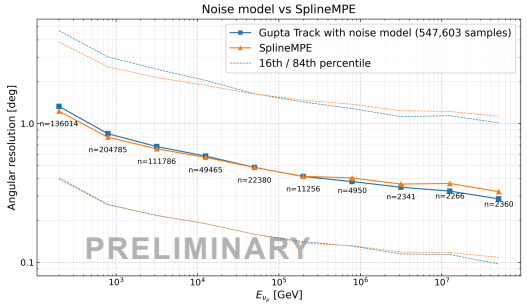
Why not every hit comes from the muon's Cherenkov photons; noise hits can shift the fit

How SplineMPE's SRT noise model, weighted by expected PEs

PDF physics + random (floor, bump) + afterpulse



Angular resolution



Now little change with the noise model; comparable to SplineMPE

Next stochastic energy losses: track + cascade likelihood over 20 m segments

Gupta-Track network achieves angular resolution comparable to SplineMPE; modeling stochastic energy losses is the next step

Transformers for Low-Energy Neutrino Physics

Hani Kimku (CAU)

Muon veto & PID Transformers

Muon veto
veto-region pulses

PID
pulses near vertex

↓

CLS	Event	P_1	P_2	...	P_n

↓

Transformer encoder

↓

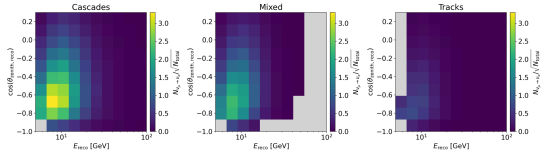
P(μ) **P(track)**

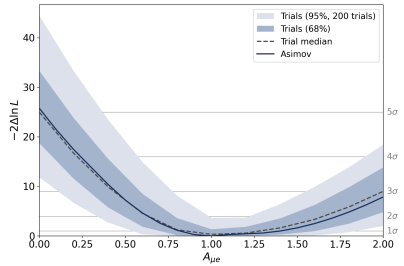
ν_e efficiency
95%
(official 68%)

AUC
0.810
(GNN 0.787)

ν_e appearance analysis

ν_e flux at detector = $\Phi_e P_{ee} + A_{\mu e} \Phi_\mu P_{\mu e}$

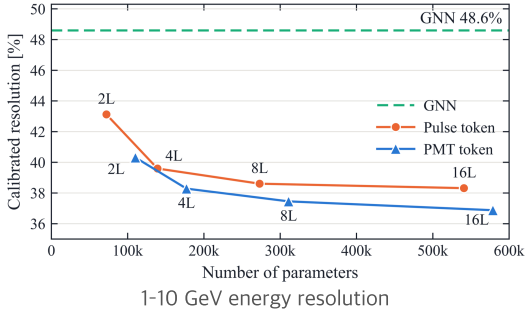




$A_{\mu e} = 0$ rejected at
5.0σ
(expected)

IceCube Upgrade Transformer

Task energy and direction at a few GeV
Token one per pulse, or one per hit PMT
Next self-supervised pretraining



1-10 GeV energy resolution

Pulse token
38.3%

PMT token
36.9%

Transformer-based event selection and reconstruction support ν_e appearance studies and low-energy physics with the IceCube Upgrade

Photon Tables and Cascade Reconstruction

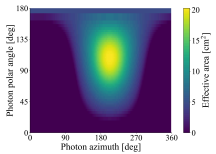
Minsu Kwak (CAU)

Per-PMT photon tables

Goal expected light and timing at every PMT
Sim photon propagation in South Pole ice
Fit smooth spline tables, one per PMT



DOM · 1 PMT mDOM · 24 PMTs D-Egg · 2 PMTs

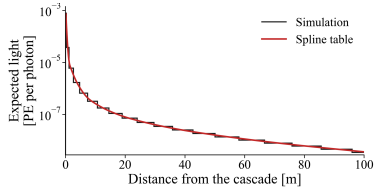


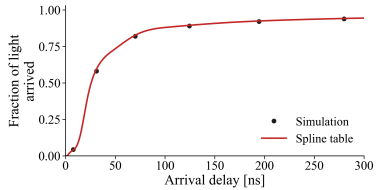
Simulated angular response of one mDOM PMT

PMT tables	Source positions
26 (24 + 2)	**1,134**

Spline fit vs. simulation

Case one mDOM PMT, one source position
Light expected light vs. distance
Time photon arrival-time distribution

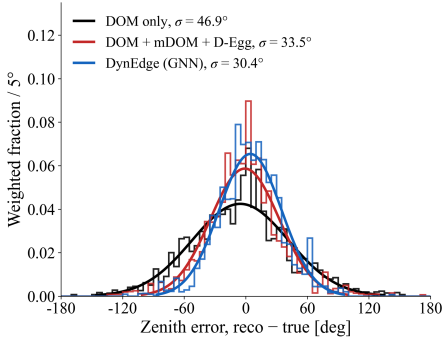




Light, median difference	Arrival time
1.2%	**≤ 1.5%**

Upgrade Monopod reconstruction

Task energy, direction, position of cascades
Test 2,199 simulated ν_e events, 1–300 GeV
Next neural-network photon tables



Zenith error at 1-10 GeV, Gaussian width σ

Zenith σ, 1–10 GeV	Energy error, 1–10 GeV
46.9° → 33.5°	**72% → 32%**

Per-PMT photon tables enable Upgrade cascade reconstruction with improved zenith and energy resolution in simulation

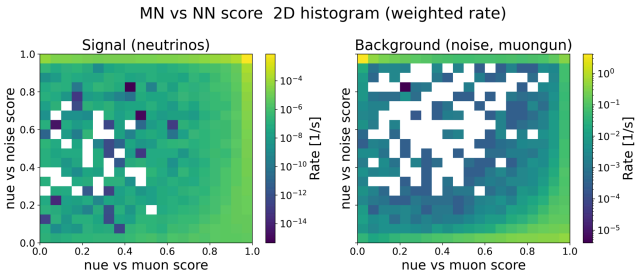
DeepCore L3 Filter and ν_e Seasonal Modulation

Sooa Kim (CAU)

DeepCore L3 filter study

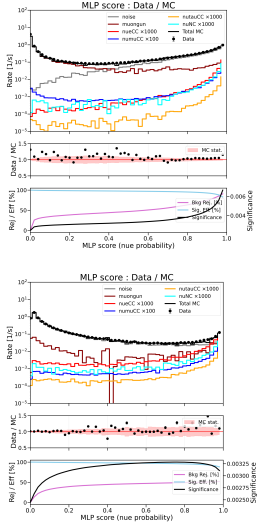
Goal L3 filter study for the IceCube Upgrade

Study variable distributions, cut scan, significance
data–MC comparison
MLP-based variable combination



MLP classifier score combining 12 L3 variables
at 99.4% noise rejection

muon rejection	ν_e efficiency
93.1% → 94.4%	**58% → 81.8%**



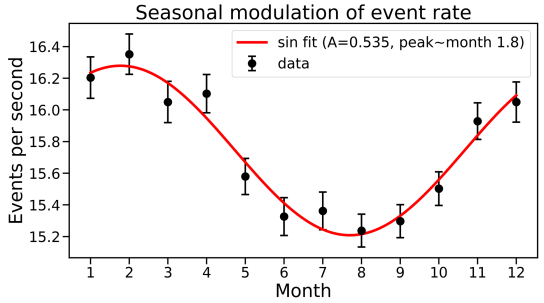
MLP score, data / MC

ν_e seasonal modulation

Goal seasonal modulation of atmospheric ν_e

Now modulation mechanism study; atmospheric muon annual modulation checked

Next Transformer-based PID, better atmospheric ν_e identification, then the ν_e modulation



Annual modulation of atmospheric muons

MLP selection retains more ν_e events at fixed noise rejection, while atmospheric-muon studies prepare for ν_e seasonal-modulation measurements

Summary

IceCube is a multipurpose observatory

Neutrino astrophysics and oscillations are major research areas,
alongside cosmic rays, dark matter, new physics, and Earth and atmospheric science

The Upgrade and Gen2 will extend these capabilities

The Upgrade targets better calibration and low-energy neutrino measurements
Gen2 aims for greater source sensitivity and higher-energy reach

The Korean group contributes to both physics and detector performance

Neutrino source searches and atmospheric-neutrino studies,
with contributions to calibration, reconstruction and event selection

Thank you



With Francis Halzen · Madison, Fall 2026