Status of IceCube-Gen2

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Science goals for IceCube-Gen2

- Discover sources of astrophysical neutrinos
- Identify sources of high energy cosmic rays
- More precise measurements of neutrino properties
- Astrophysical tau-neutrino discovery
- Set limits or discover GZK neutrinos
- BSM physics
Extending IceCube

IceCube
86 strings
125 m inter-string distance
60 OMs per string
0.9 km³ volume

“Sunflower” layout
120 new strings
240 m inter-string distance
80 OMs per string
8 km³ volume
Envisioned IceCube-Gen2 Facility
Envisioned IceCube-Gen2 Facility

- PINGU: 40 strings
- IceCube-Gen2 High Energy Array (HEA): 120 strings
- IceCube-Gen2 Cosmic Ray Array (CRA): ~800 stations
- IceCube-Gen2 Radio Array: 120 stations

(Proposed)

~20 km
IceCube-Gen2 Phase 1: The next step

Proposal to add 7 additional strings

Instrument with multi-PMT digital optical modules (mDOMs)
  • Better directionality
  • Doubles photocathode area

Inline with physics goals of the Precision IceCube Next Generation Upgrade (PINGU)
IceCube-Gen2 Phase 1: Oscillation sensitivity

Latest DeepCore result

![Graph showing oscillation sensitivity with various data points and contours.](image)
IceCube-Gen2 Phase 1: Oscillation sensitivity

T2K best-fit assumed

- IceCube 2017
- Super-K 2015
- MINOS w/atm
- NOνA 2017
- T2K 2017
- Gen2-Phase1 (3 yr proj.)
  [T2K 2016 assumed]
IceCube-Gen2 Phase 1: Oscillation sensitivity

NOvA best-fit assumed

- IceCube 2017
- Super-K 2015
- MINOS w/atm
- NOvA 2017
- T2K 2017
- Gen2-Phase1 (3 yr proj.) [NOvA 2017 assumed]

90% CL contours [NO]

\( |\Delta m_{32}^2| (10^{-3} \text{ eV}^2) \)

\( \sin^2(\theta_{23}) \)
IceCube-Gen2 Phase 1: Oscillation sensitivity

Latest DeepCore result

![Graph showing recent DeepCore results](image_url)

Precision significantly improved over DeepCore

Latest DeepCore result

![Graph showing recent DeepCore results](image_url)
Ongoing hardware R&D

**D-Egg: dual-PMT optical module**  
A. Ishihara, NU073; A. Stoessl, NU111

**mDOM: multi-PMT optical module**  
L. Classen, NU082

**WOM: wavelength-shifting optical module**  
P. Peiffer, NU053

**IceTop scintillator upgrade**  
S. Kunwar, CRI148

**IceACT: low-threshold air shower veto**  
J. Auffenberg, NU041

Optical modules: more photons per unit cost, more information per photon

Surface detector: threshold vs. duty cycle

J. van Santen  
(ICRC2017)
Improved calibration system

Precision Optical CAlibration Module (POCAM) in-situ calibration devices
→ Improve knowledge of ice properties

Prototype deployed within Gigaton Volume Detector in Lake Baikal

Isotropic light source
Looking forwards: A surface veto for IceCube-Gen2

Main background in southern sky are atmospheric muons from cosmic rays

Surface veto can help tag them

Envisioned area of 75 km² – compare to IceCube’s 1km² surface veto IceTop

Around 800 stations, covering the entire detector up to zenith of 45°

Prototype stations under construction
IceCube-Gen2 sensitivity studies

Figure 4: Measurement of a muon-damping break at 1 PeV with IceCube-Gen2. The left panels show the constraints on the flavor ratio at Earth below and above 1 PeV, respectively. The points show the expected ratios at Earth from muon-damped pion decay ($n:μ:n_t = 0:1:0$) and complete pion decay (1:2:0). The dotted contours give the 68% CL allowed region, while the solid lines correspond to 90% CL. The error bars in the right panel show the 68% CL constraints on the muon-neutrino fraction at the source assuming standard oscillations over long baselines [20], while the line shows the injected flavor composition at the source.

Figure 5: Integrated sensitivity for an $E^2$ flux from a single source after 15 years of IceCube operation followed by 15 years of IceCube-Gen2. The sensitivity and trials-corrected upper limit of the all-sky point source search with 7 years of IceCube data [6] are shown for comparison. The discovery potential is typically 2.5 times larger than the sensitivity. The surface veto improves both discovery potential and sensitivity by a factor $&3$ for $\sin d$.0.5.

2.4 Point sources

While the quasi-diffuse astrophysical neutrino flux has been observed, its sources have remained too faint to detect. The significantly larger instrumented area of IceCube-Gen2 will, however, allow sensitivity to fluxes from individual sources that are fainter than current limits. Figure 5 shows integrated sensitivities and discovery potentials to an $E^2$ flux from a single source, using only through-going track events. Neutrino absorption in the Earth reduces the sensitivity towards the North Pole. In the Southern sky, overall sensitivity is reduced due to the energy threshold imposed by the surface veto and the limited target mass for neutrino interactions between the surface and the detector. Like IceCube, Gen2's best sensitivity is at the local horizon ($d = 0$), where the projected density of the instrumentation and the range of neutrino-induced muons is greatest.

3. Outlook: improved sensor designs

The performance estimates shown above were obtained with the PINGU DOM (PDOM) [21], an updated version of the IceCube DOM that uses the same 10-inch, high-quantum-efficiency PMT.
Clear distinction of the different spectra possible

Double power law $E^{-2} + E^{-2.5}$ injected flux

Number of events in each energy range

Blue error bars show the 68% range of allowed fluxes

PoS (ICRC2017) J. van Santen
Cutoff sensitivity, 3 PeV cutoff, $\gamma=2.17$

Method: inject astro+GZK neutrino flux and unfold expectations
Error bars show 68% range of allowed fluxes
Cutoff sensitivity, 30 PeV cutoff, $\gamma=2.17$

Method: inject astro+GZK neutrino flux and unfold expectations

Error bars show 68% range of allowed fluxes

Cutoff sensitivity is energy dependent, less obvious for 30 PeV cutoff
Detection of GZK neutrinos produced off CMB requires sensitivity above 100 PeV

ARA = Askaryan Radio Array

Detect radio waves produced via Askaryan effect on ice

Most optimistic GZK flux scenario

- ARA-37: 2.8 evts/yr
- IceCube-Gen2: 0.5 evts/yr

Complementary radio array: ARA

Assuming 37 radio arrays at 200 m depth
Summary

The future of in-ice neutrino telescopes is IceCube-Gen2
Envisioned components include PINGU, large surface array, and complementary radio array

IceCube-Gen2 Phase 1 is the next step
Proposed 7 string expansion with densely-spaced mDOMs
Aligns with PINGU science goals ➔ Improved oscillation sensitivity

Ongoing hardware development to improve DOM design and surface veto detectors

A lot more left to do and to discover!

Credit: Martin Wolf, IceCube/NSF
Backups
Sensitivity improvements from new DOM designs
Flavor ratio improvement