From the IceCube Upgrade to IceCube-Gen2

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On behalf of the IceCube-Gen2 Collaboration

August 26, 2024

ICECUBE GEN2

Multimessenger Astrophysics - from GeV to EeV

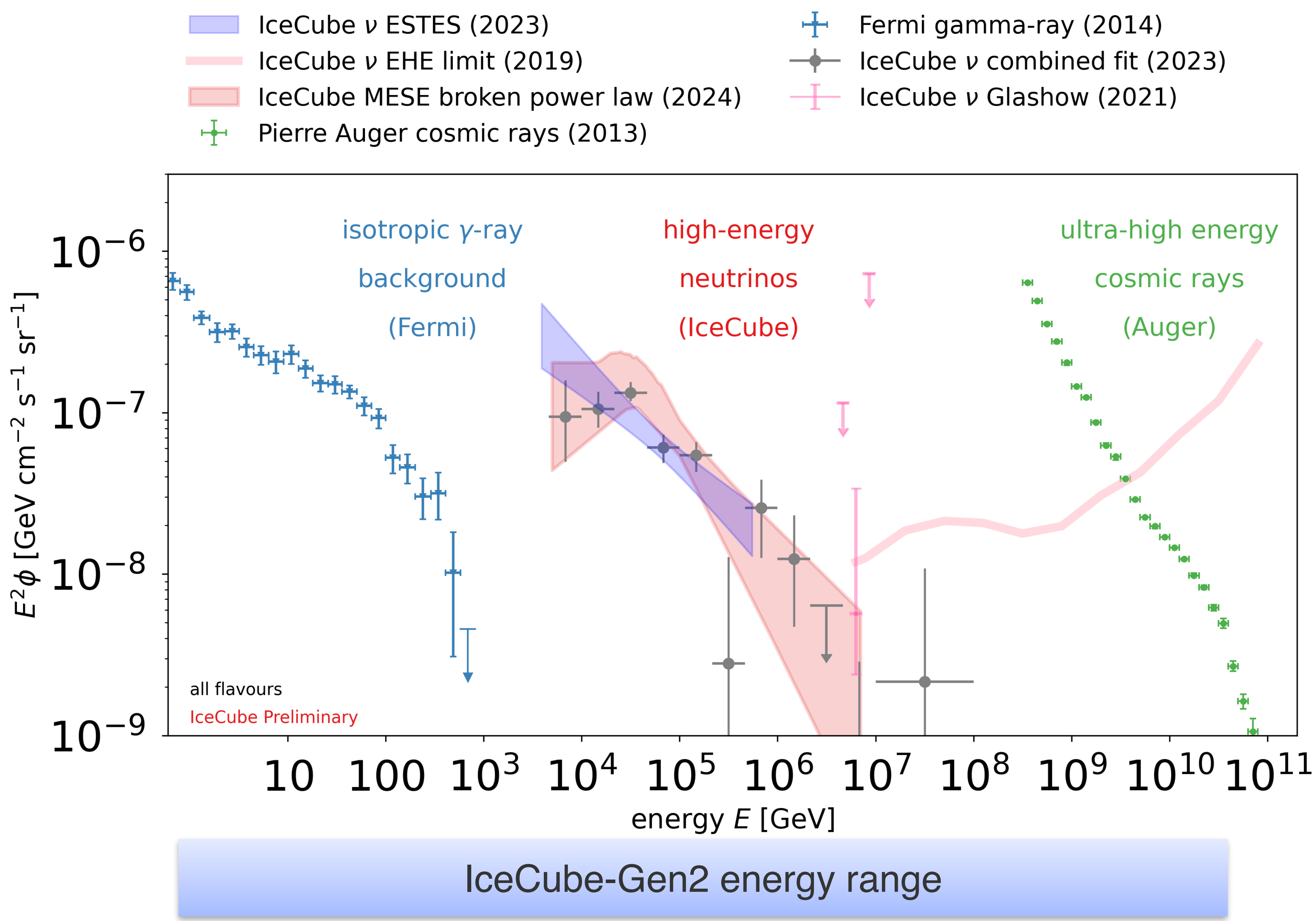


figure:
courtesy Lu Lu

See also talks by
Vedant Basu,
second session today.
Lu Lu tomorrow.

23 IceCube talks

and plenary talks by
Brian Clark,
Ke Fang and
Elisa Resconi
on Wednesday.

IceCube future:

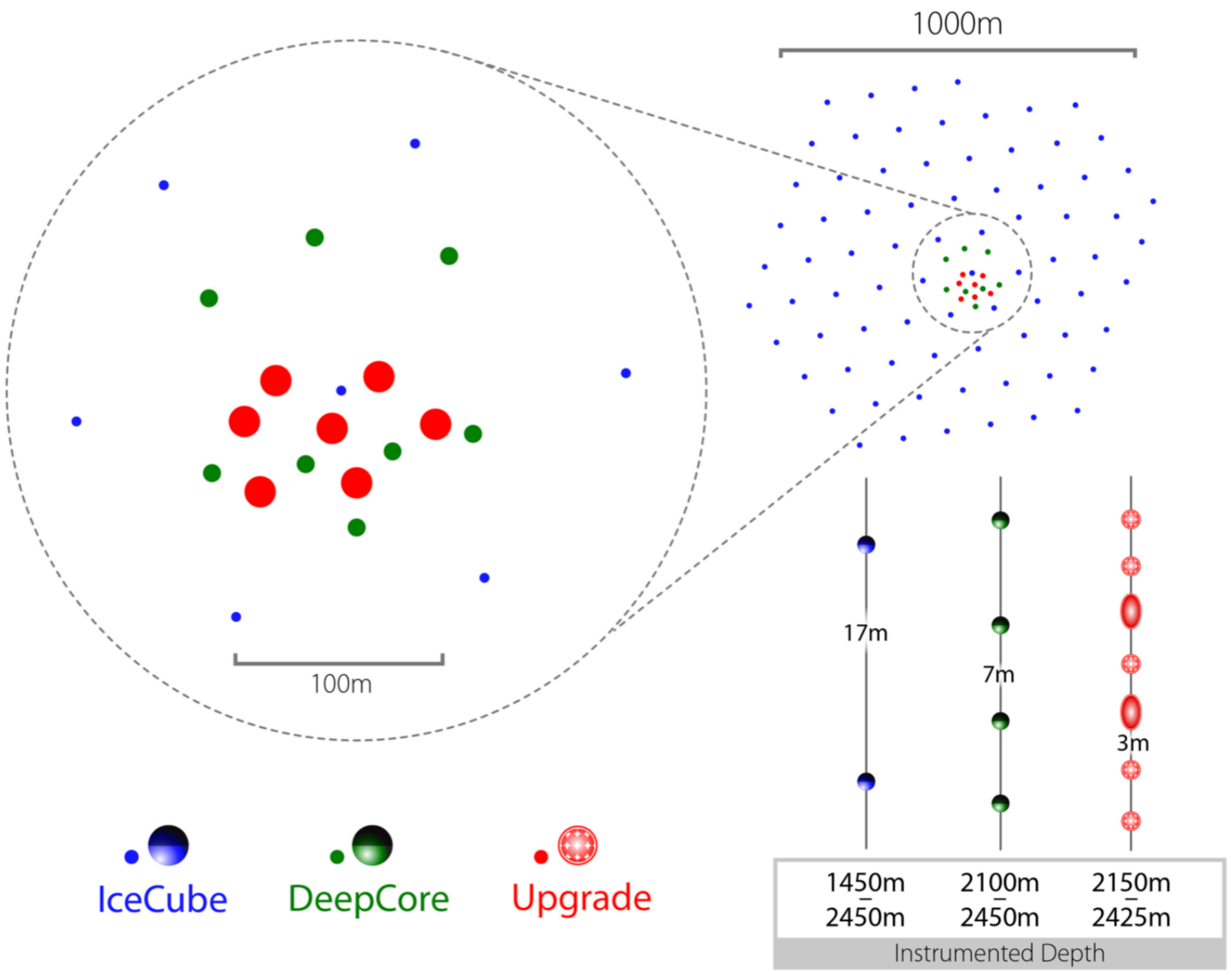
Continued operation of the IceCube Neutrino Observatory.
The digital architecture of IceCube allows seamless “integration” of future upgrades.

Upgrades:

Phase 1: The IceCube Upgrade (in progress)

Phase 2: IceCube-Gen2 (goal)

Phase 1: The IceCube Upgrade



Scope:

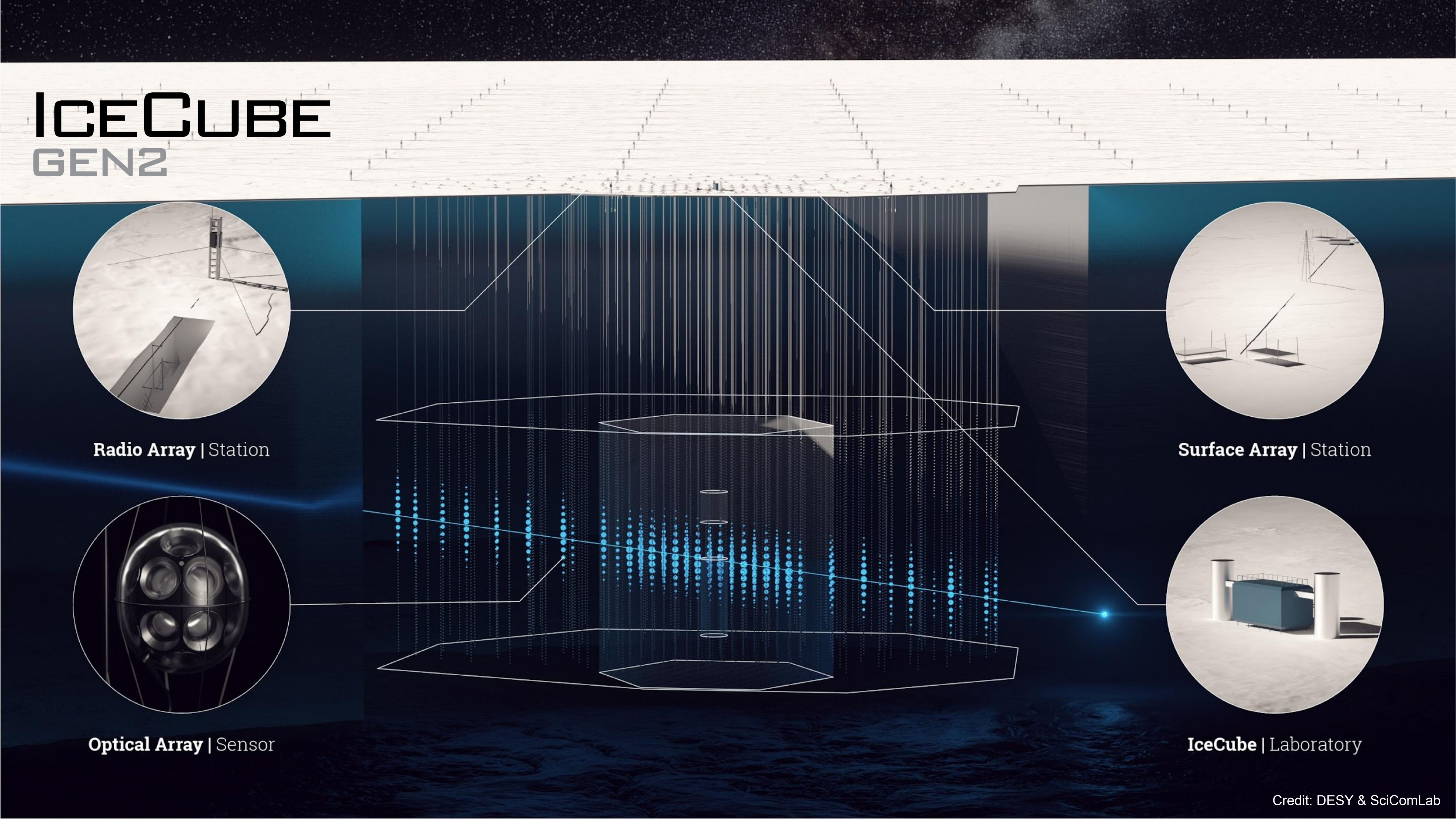
- Seven new in-fill strings, densely instrumented.
- Target mass: 2 Mt.

Objective:

- Precision measurement of atmospheric neutrino oscillations, mass hierarchy.
- Improved calibration of IceCube
- Technology development for developments beyond the Upgrade.

Ongoing construction;

Scheduled completion 2025/26.


ICECUBE
GEN2
Radio Array | Station
Surface Array | Station
Optical Array | Sensor
IceCube | Laboratory
Credit: DESY & SciComLab

IceCube-Gen2: Point Sources

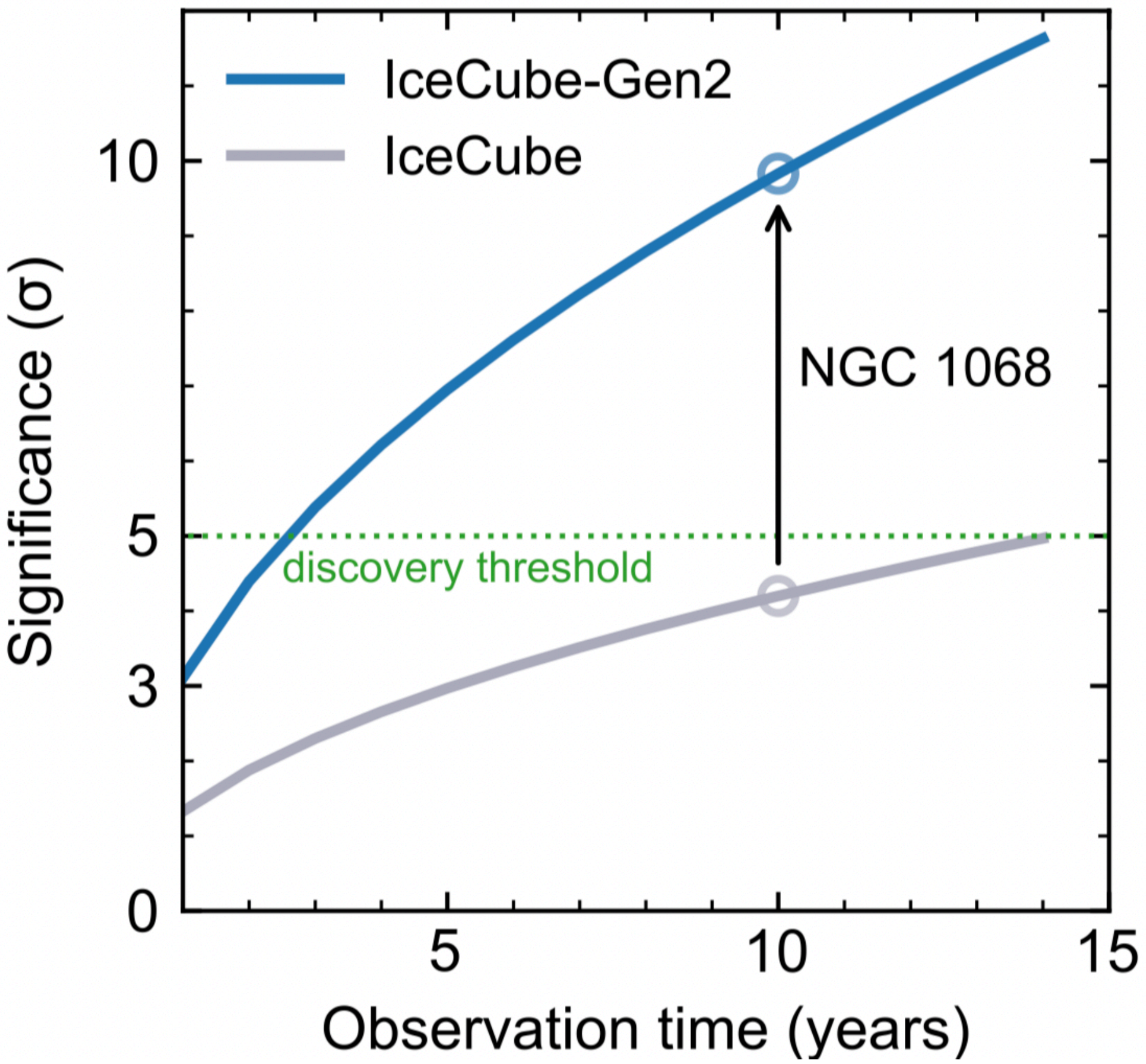
- 5 × improvement in effective area
- 2 × improvement in angular resolution

IceCube-Gen2 will allow to firmly discover the brightest AGNs on the neutrino sky.

NGC1068: 10 σ after 10 years:

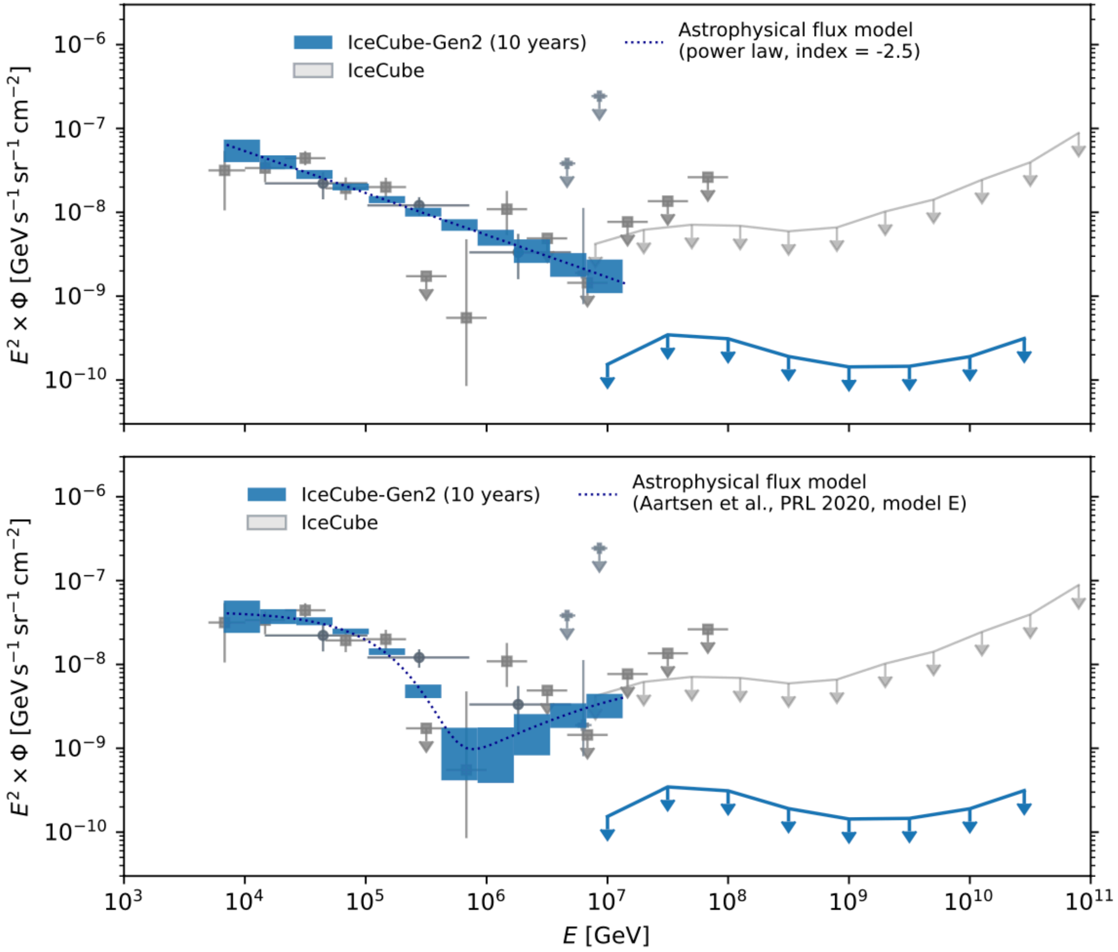
Precise measurement of the spectral shape of the neutrino emission

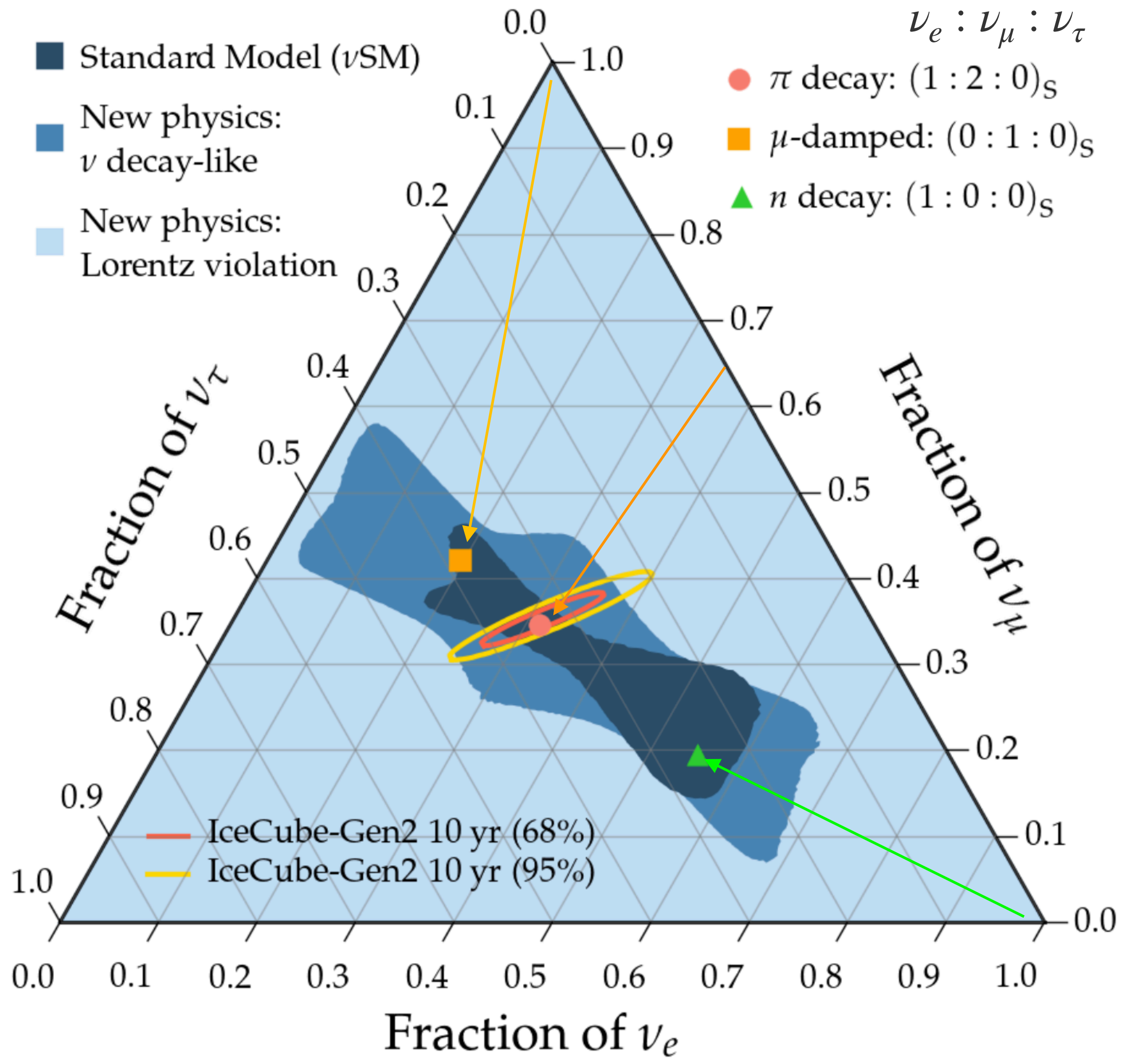
https://icecube-gen2.wisc.edu/science/publications/tdr/



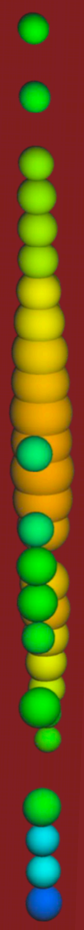
Understanding the Origin of Cosmic Rays/Neutrinos at high energies

Precise mapping of cosmic neutrino spectrum from 1 TeV to 1 EeV
Energy dependent flavor measurements



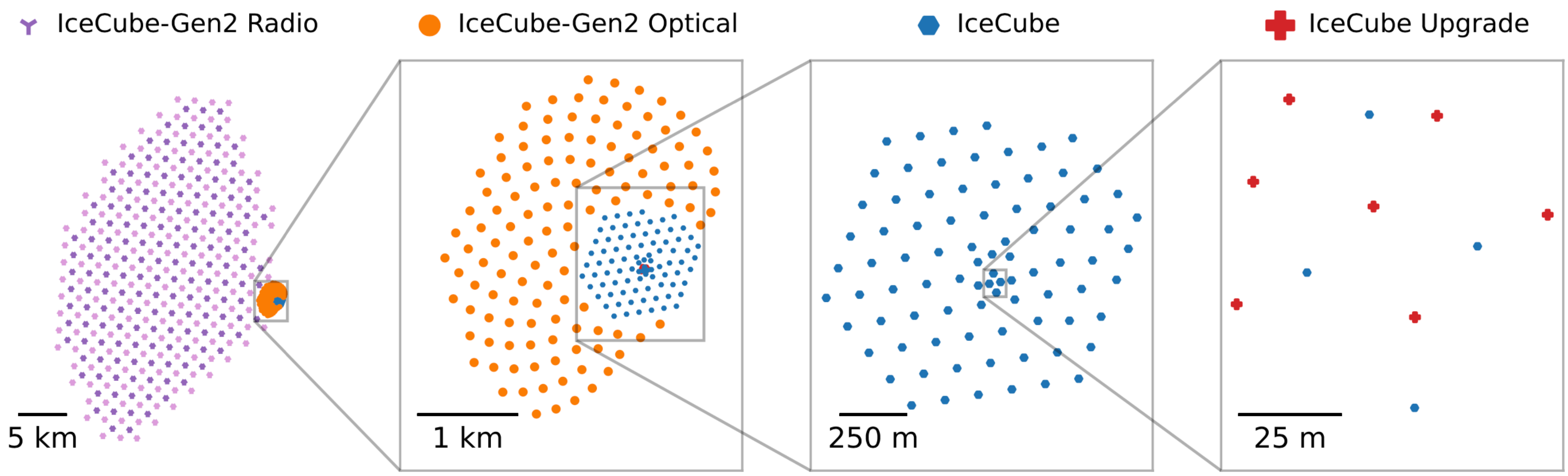


Adapted from Mauricio Bustamante, John F. Beacom, Walter Winter, PRL 2015.



IceCube-Gen2: A wide-band observatory

Optimizing scales for leading sensitivity from 10^9 to 10^{20} eV



>30 PeV

> 3 TeV

>0.5 TeV

completed in 2011

> GeV

under construction,
deployment in Dec. 2025

IceCube-Gen2

Technical Design Report

Part I: Science and Conceptual Design

Part II: Detector & Performance

Part III: Detector Construction and
Logistical Support Requirements

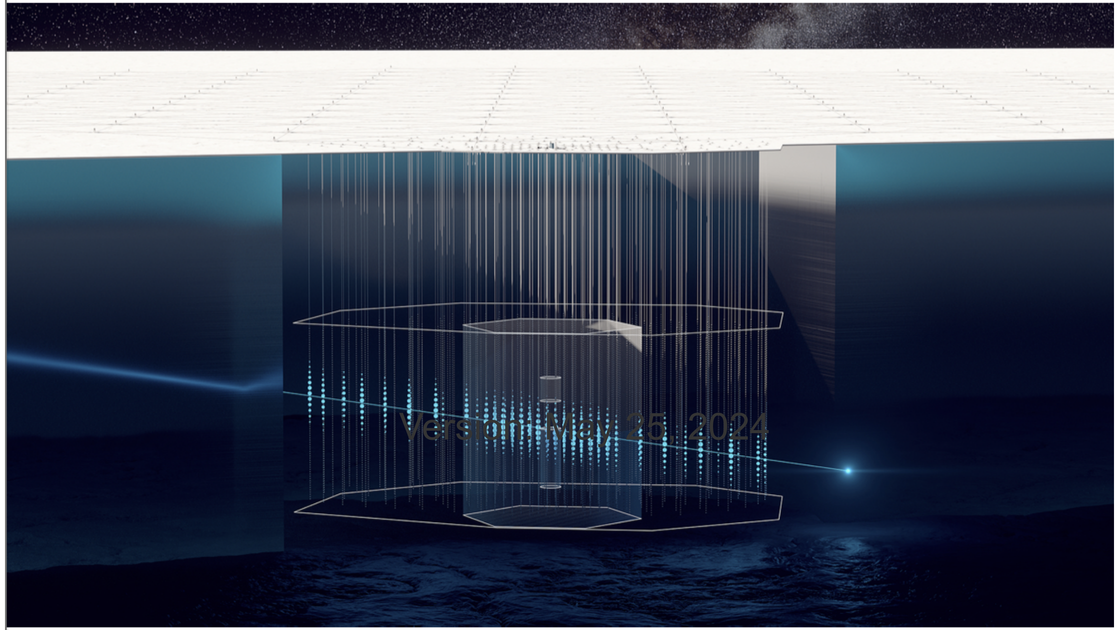
Download here:

https://icecube-gen2.wisc.edu/science/publications/tdr/

(350 pages)

ICECUBE GEN2

ICECUBE-GEN2 TECHNICAL DESIGN



The IceCube-Gen2 Neutrino Observatory

Parts I and II

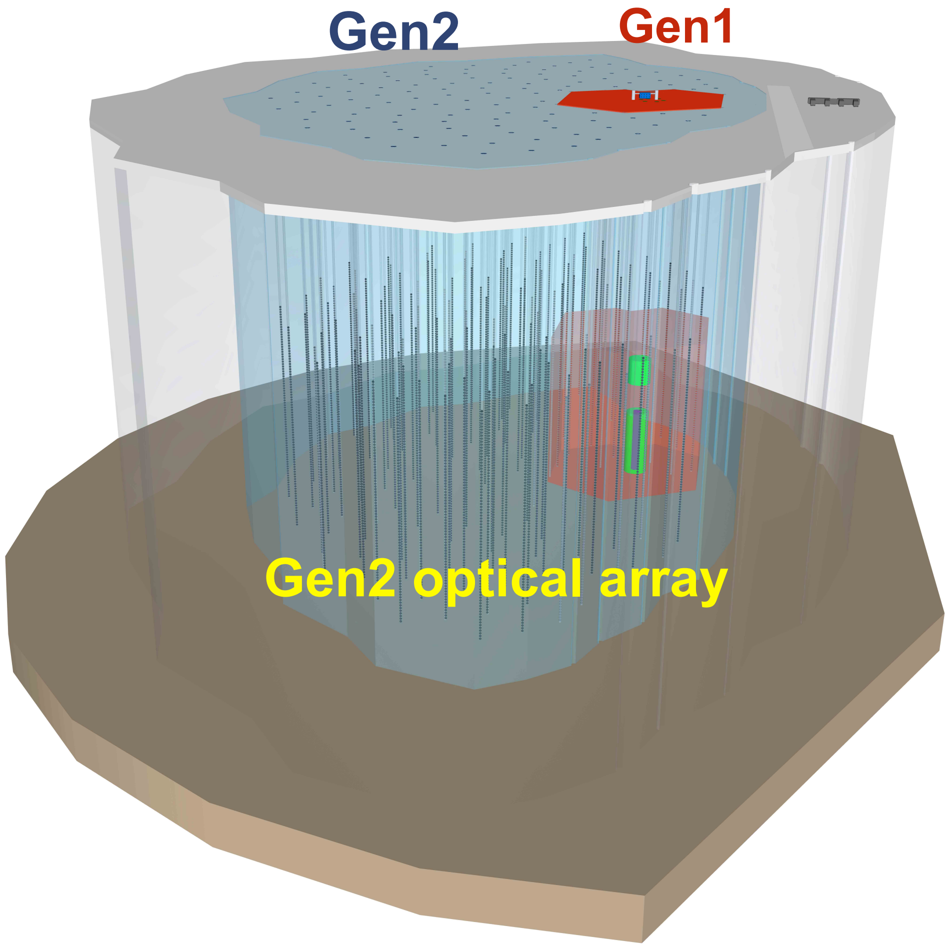
~~(Part III will be released at a later time.)~~

and now: Part III

Version: May 25, 2024

Scope: 1. The Optical Cherenkov Array

The main detector component.

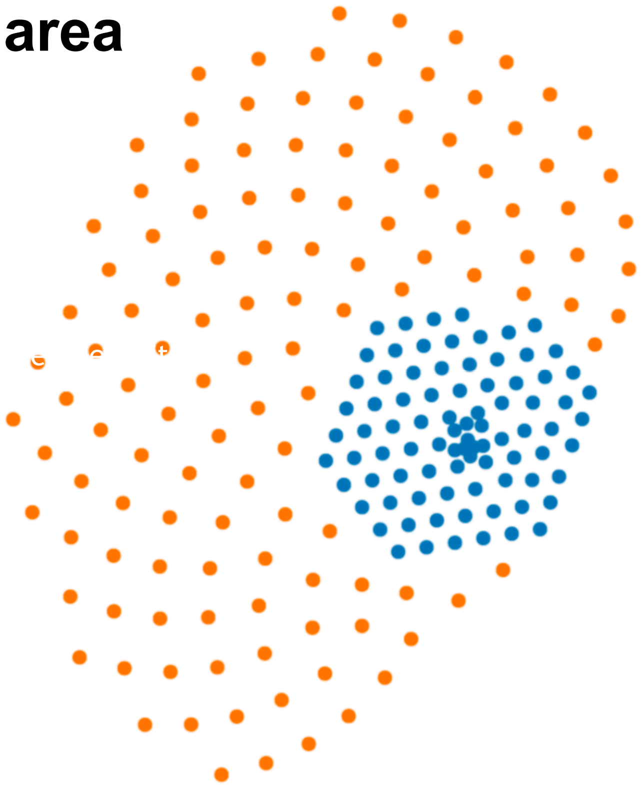


Surface Area: ~6.5km^2

Instrumented Volume: 8 km^3

9600 optical sensors
—> 8 x Photon detection area

120 strings



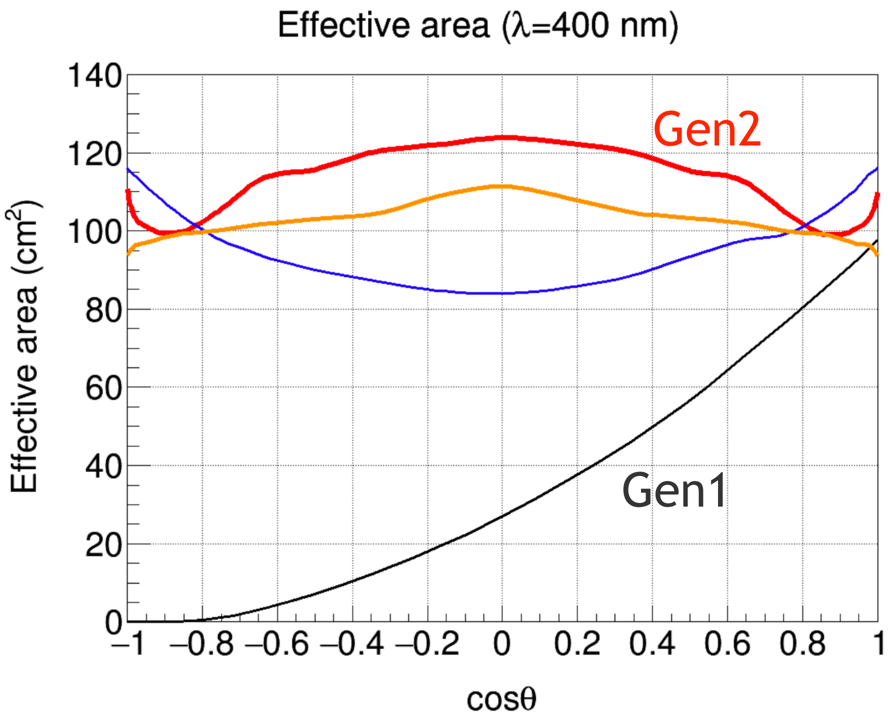
The Gen2 Digital Optical Module

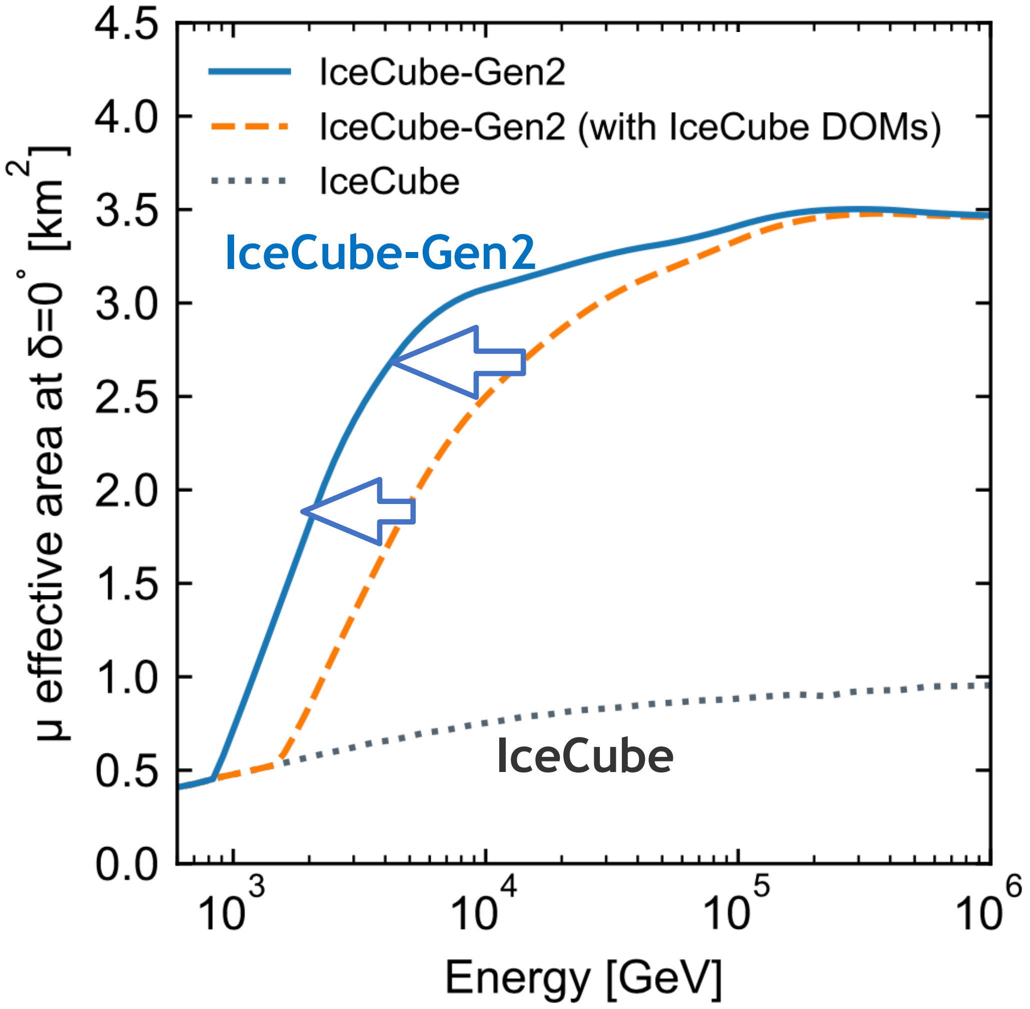
- Evolution of the design developed for the IceCube Upgrade (mDOM / D-Egg)
- Smaller diameter (bore holes)
- 4 x IceCube Gen1 sensitivity
- Low power consumption

New 4-inch PMTs, with digitizer on base.

Higher Sensor sensitivity —> Larger Muon Effective Area

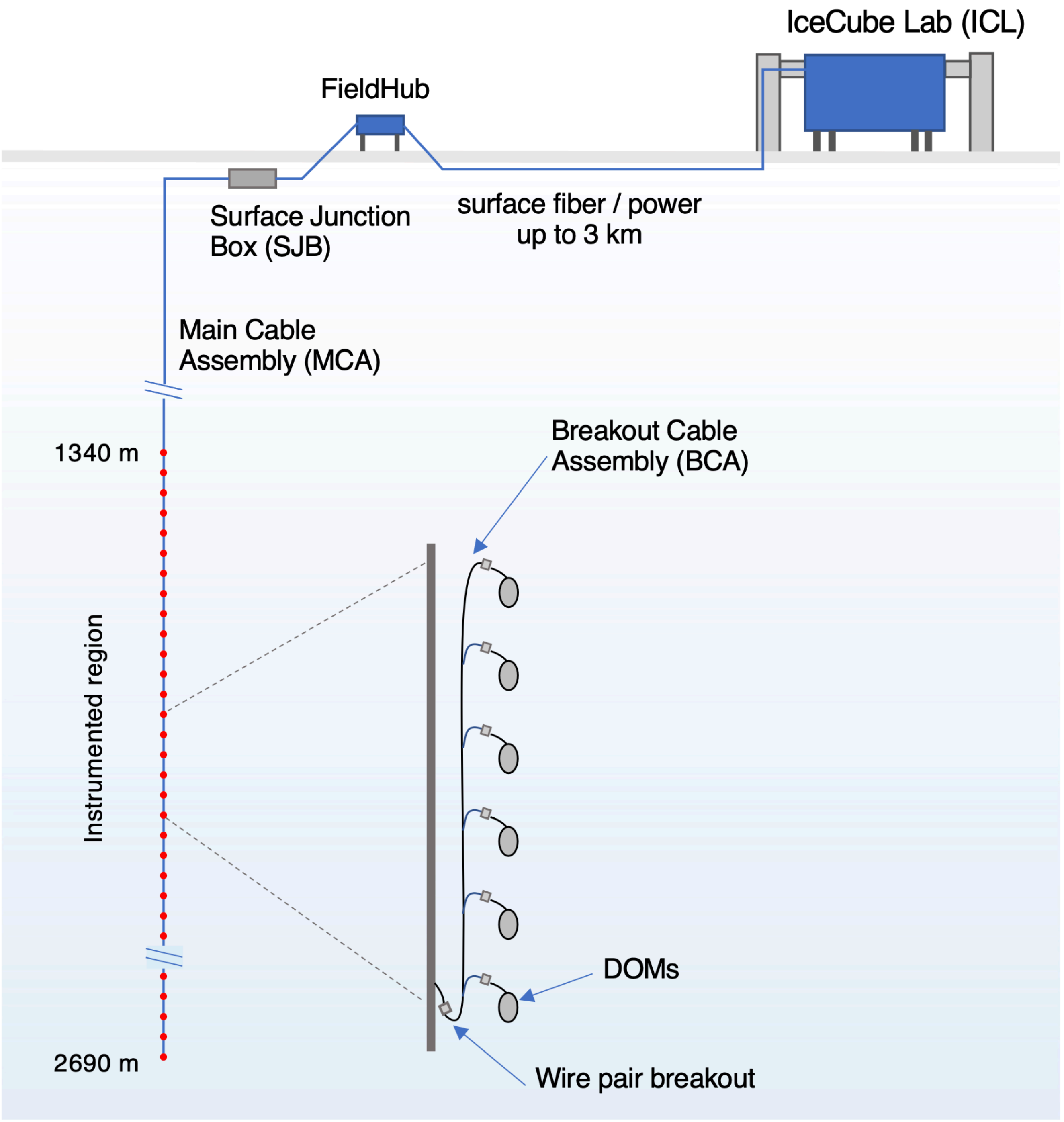
Factor 4 more photons detected
—>
- Lower energy threshold
- Angular resolution: 0.1 - 0.3°





Power and communications architecture

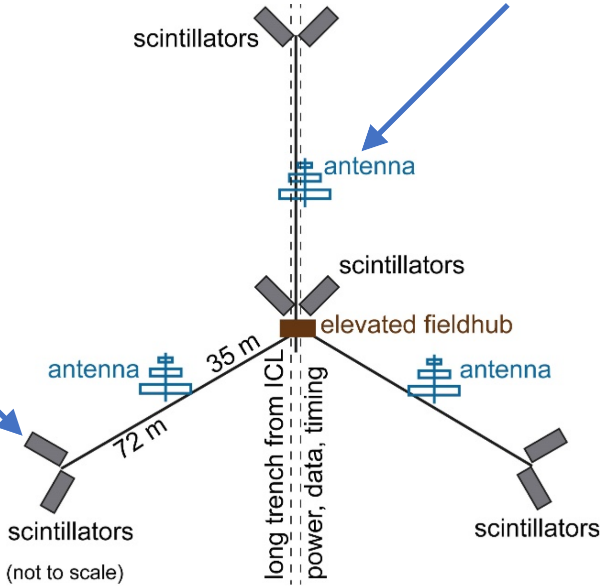
- “Fieldhub” on the ice.
- Revised trigger architecture
- Fewer copper cables are needed (60% less).
- This means also a big reduction of cargo (one million lb less.)

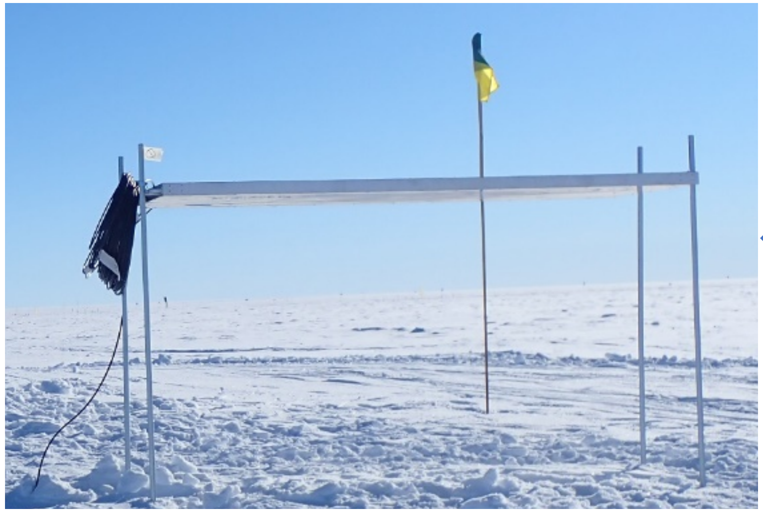


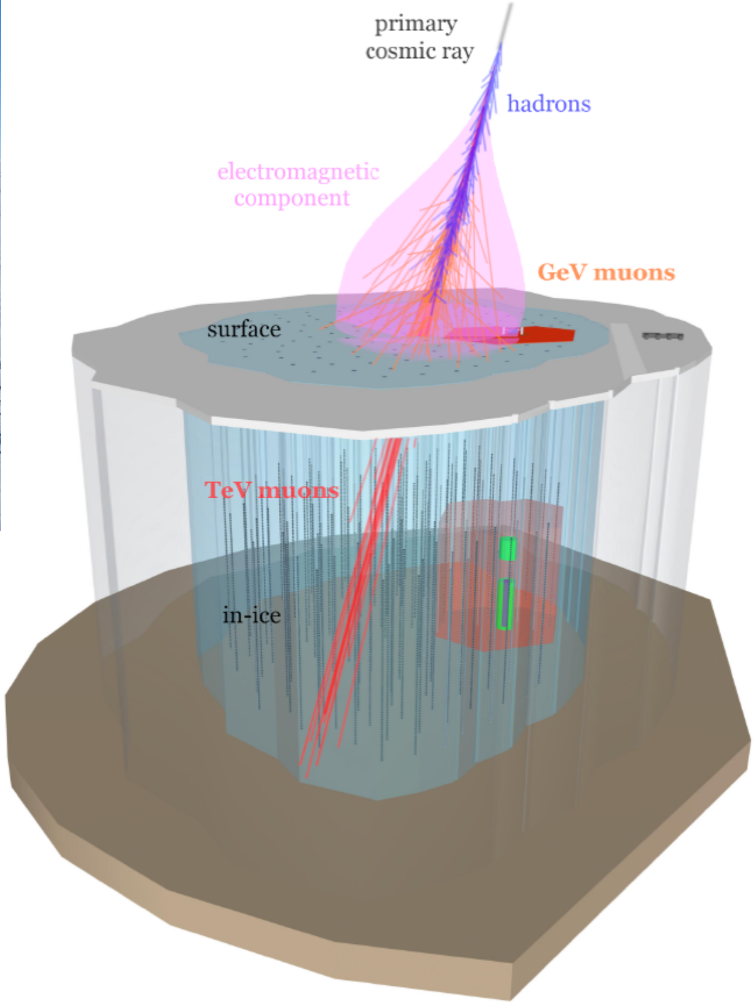
ICECUBE GEN2

Scope: 2. The Surface Array

- Veto for larger and purer sample of PeV neutrino candidates
- High accuracy for cosmic rays in the PeV to EeV region
  - particle physics in air showers
  - cosmic-ray astrophysics

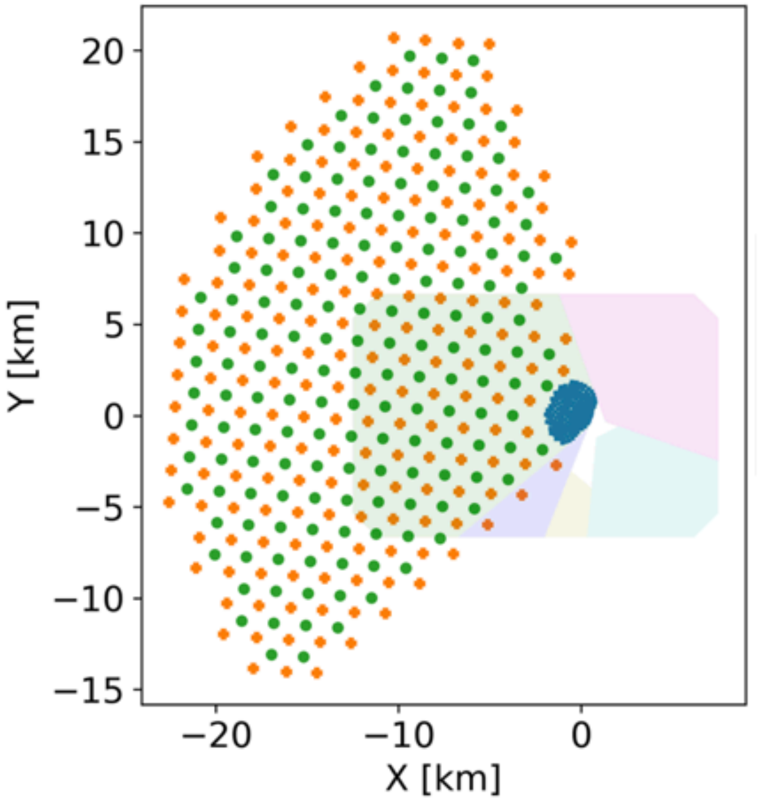






Scope: 3. The Gen2 radio array

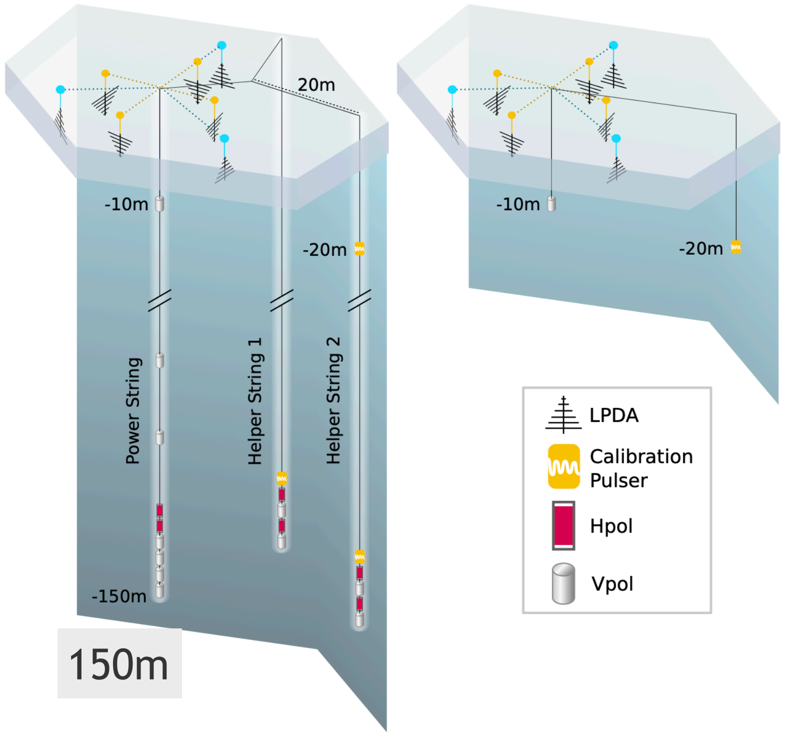
Energy range from 30 PeV to well beyond EeV



361 stations

Area: 500 km²

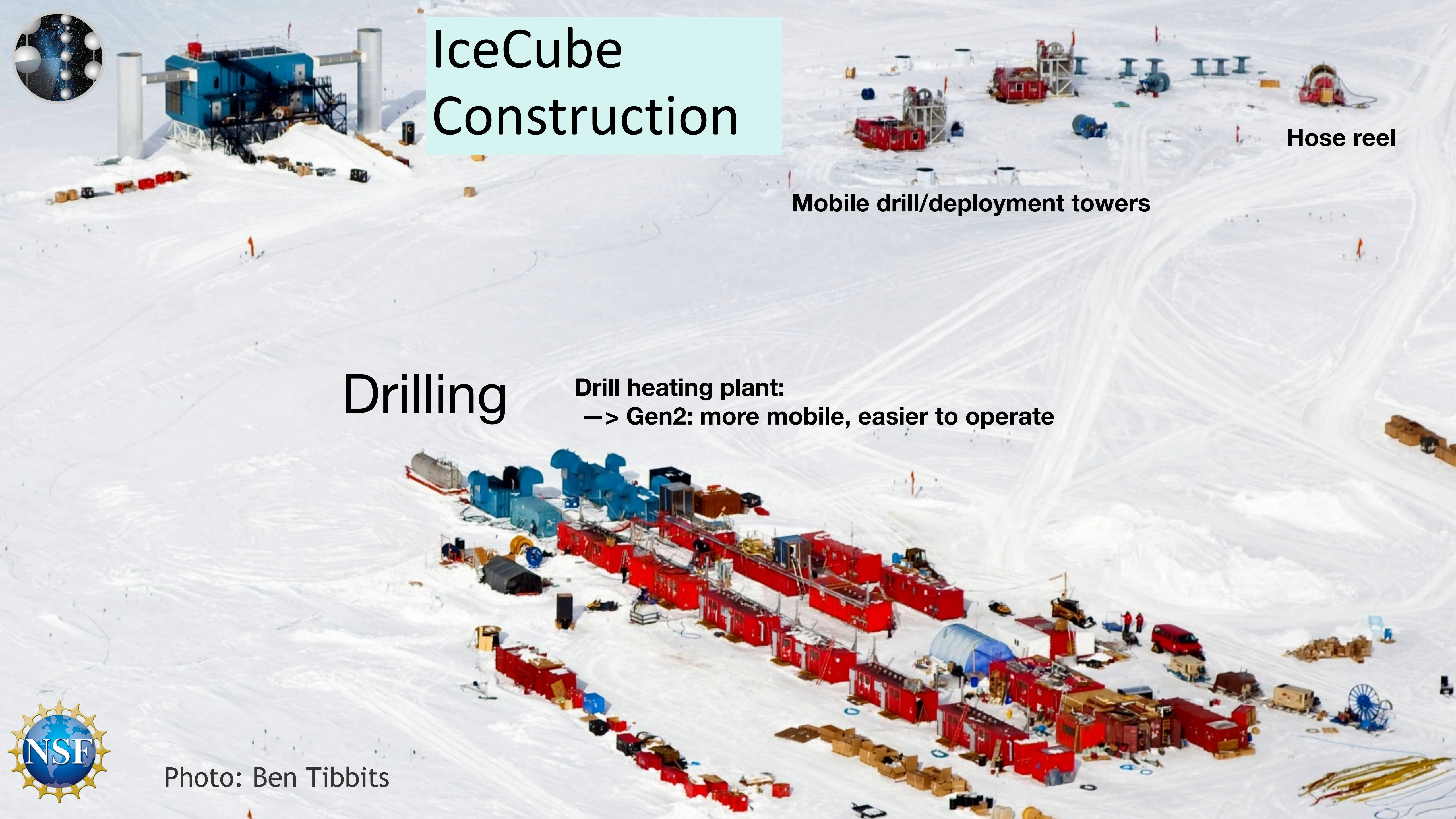
Ice target: 1000 km³



The phased array trigger was successfully tested in ARA, is now used in RNO-G.

RNO-G:

- Currently in construction in Greenland
- 28 stations, 7 deployed (10% of Gen2)
- Serves as prototype array for Gen2.


IceCube Construction
Mobile drill/deployment towers
Hose reel
Drilling
Drill heating plant:
—> Gen2: more mobile, easier to operate
Photo: Ben Tibbits

“A harsh environment for life, an ideal environment for research”

The issue of logistical support for highly recommended projects has been a recent discussion point.
An example is this article in the Symmetry magazine.

[symmetry magazine]

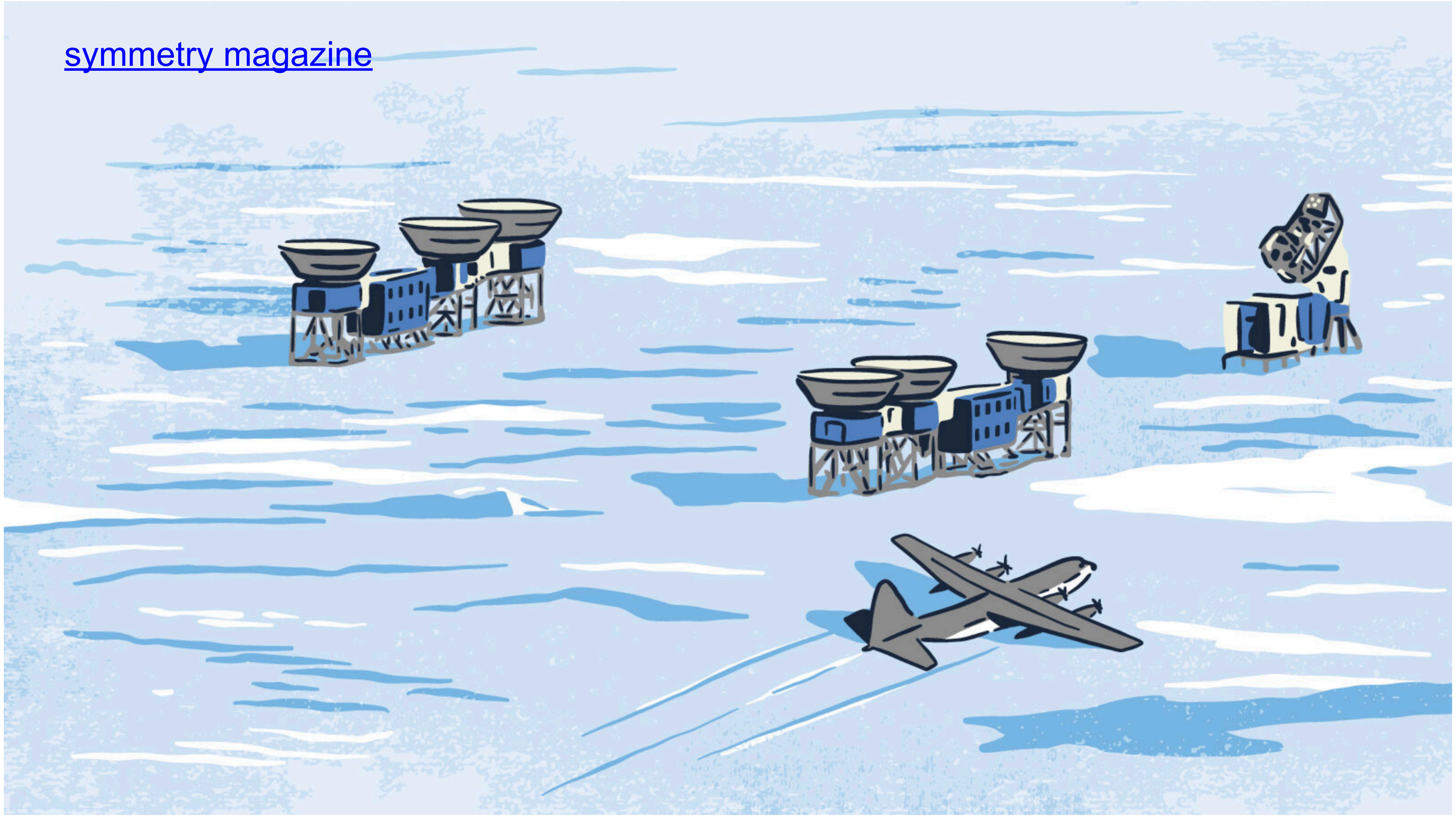


Illustration by Sandbox Studio, Chicago with Steve Shanabruch

03/26/24 | By Madeleine O'Keefe

The Particle Physics Project Prioritization Panel recently recommended, among their top priorities for the next decade, moving forward with two experiments based at the South Pole.

Logistical Support

1. Logistical Support provided by **NSF's Office of Polar Programs made IceCube possible**.
2. IceCube Gen1: 9 million lb of cargo + fuel, 300 LC 130 missions. Construction occurred simultaneously with the South Pole station completion and South Pole Telescope construction.
3. IceCube-Gen2 **Logistical Support requirements are well understood**.
4. **Strategies for logistical support exist**.
5. All logistical **support will be on the project budget. Successful logistics will require high-level prioritization and strategic planning at NSF's Polar Program**.

C17 transport (J. Donnenfeld)

Amundson Scott South Pole station (wikip.)

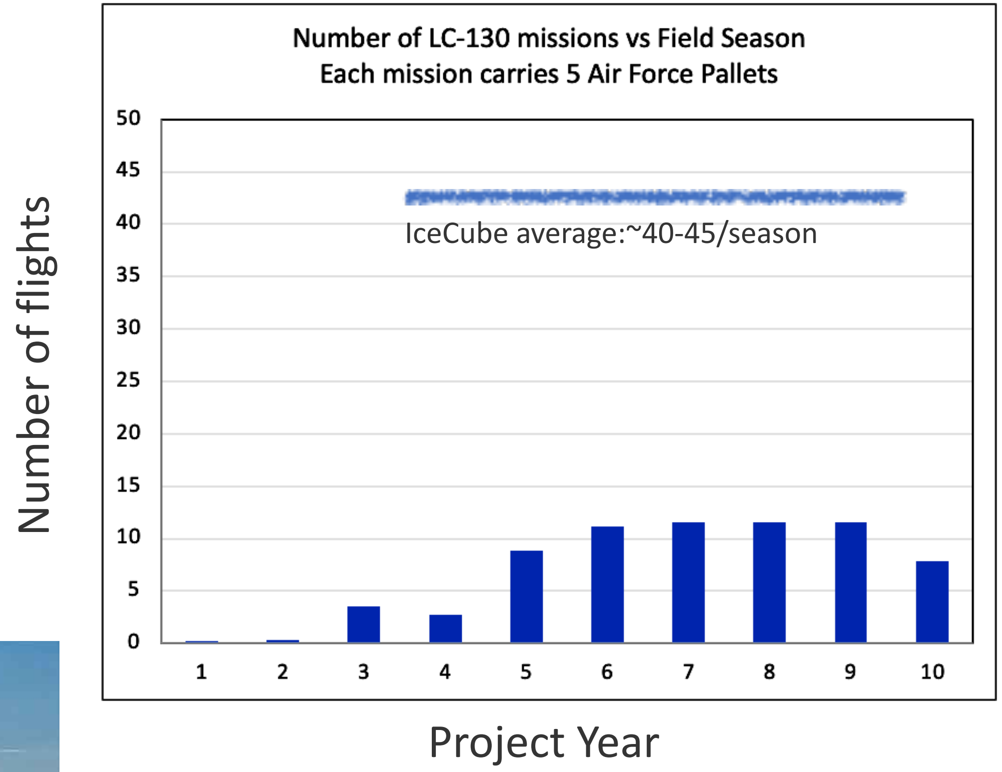
Meeting logistical challenges

of projects like IceCube-Gen2 and CMB-S4:

	Challenge	Solution strategy
Cargo	◉ The fleet of LC130 aircraft is not what it used to be by far.	➡ Shift transport of fuel and cargo from planes to overland transport. Upgrade of "South Pole Traverse" capacity. ➡ Add LC-130J planes. Two new planes are requested in Senate appropriations committee defense budget.)
Population	◉ South Pole station main building houses only 150 people.	➡ Temporary summer housing. This straightforward, has been done before, for several years up 280 people population.
Power	◉ Current generator has little headroom. 100 KW are needed.	➡ Factor in power needs as a margin in the **South Pole Masterplan**. Significant additional power (>10kW) is needed only in year 5 of IceCube-Gen2 construction (not before ~2033)
South Pole Infrastructure maintenance, upgrades	◉ Can it be done in parallel with Science?	➡ We believe it is critical not to defer science until after modernization. Coordinating with the science community will be important. Logistics support funding is largely built into project budgets.

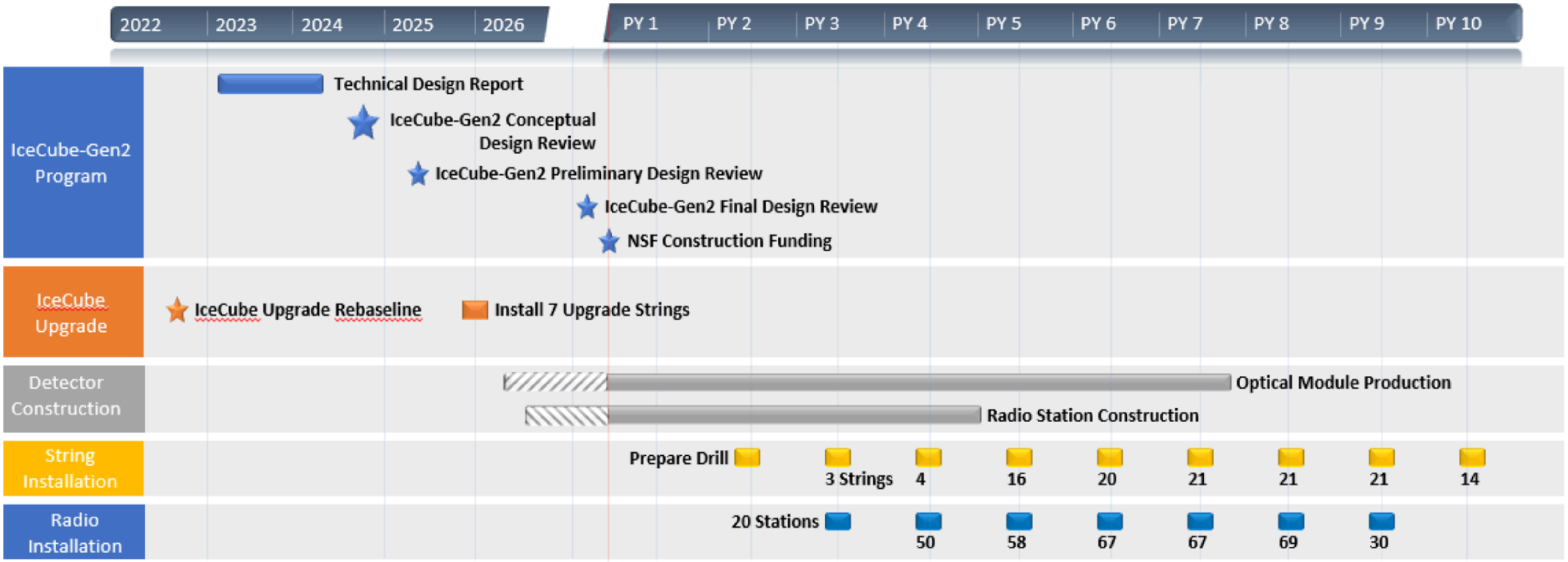
Minimize Logistical Support: LC-130 flights

LC 130 aircraft



Send almost all (>95%) Cargo by overland traverse!

Timeline

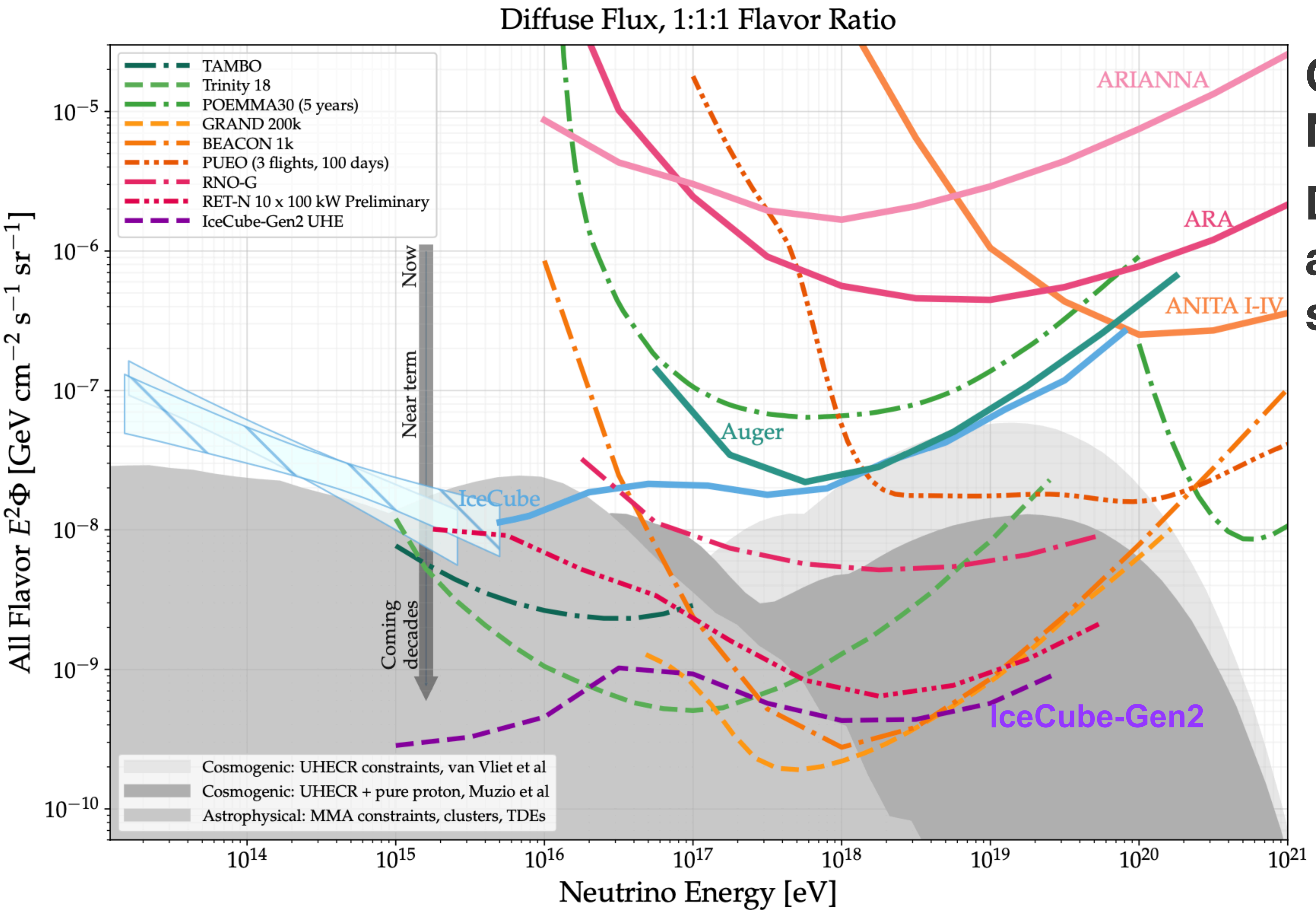


- Assumes Conceptual Design Review in 2024, Preliminary Design Review in 2025, Final Design Review and Construction Start in 2027
- 10 year project – with NSF funding starting in April 2027 / last string installed in the 36/37 Field Season
- Allows for in-kind detector production after Preliminary Design Review but before Final Design Review/NSF Construction Funding
- Note that Radio / Drill schedules are ~ independent – can move independent of each other

Summary

- Neutrino astronomy exceptionally promising.
- IceCube continues to operate with ~99% of all sensors.
- IceCube-Gen2 is the natural next step.
- Dedicated and growing international collaboration.
- International contributions: 1/2 of instrumentation.
- Technical Design Report complete.
- Next step: IceCube-Gen2 project development towards Preliminary Design Stage. Resolve logistical questions in the process.

Backup



Cosmic Neutrinos:

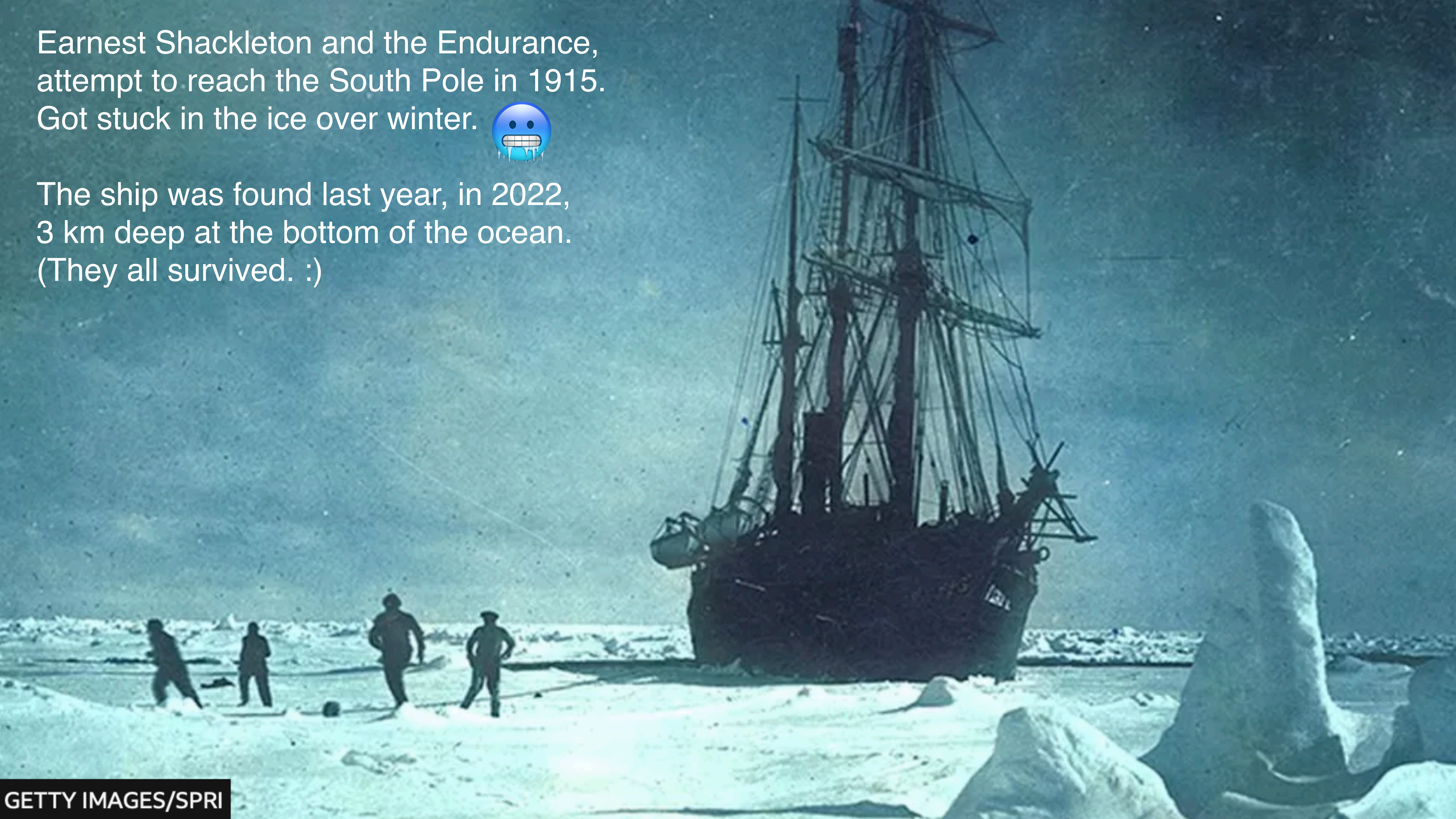
Diffuse fluxes and sensitivities

High-Energy and Ultra-High-Energy Neutrinos: A Snowmass White Paper

https://arxiv.org/abs/2203.08096

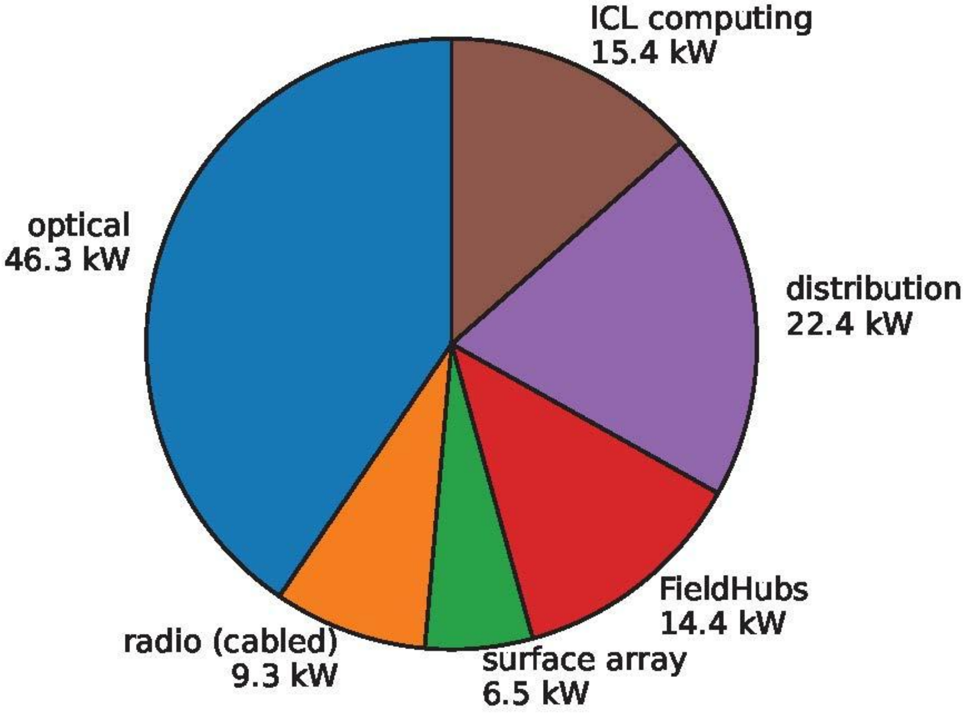
Earnest Shackleton and the Endurance, attempt to reach the South Pole in 1915. Got stuck in the ice over winter. 🥶

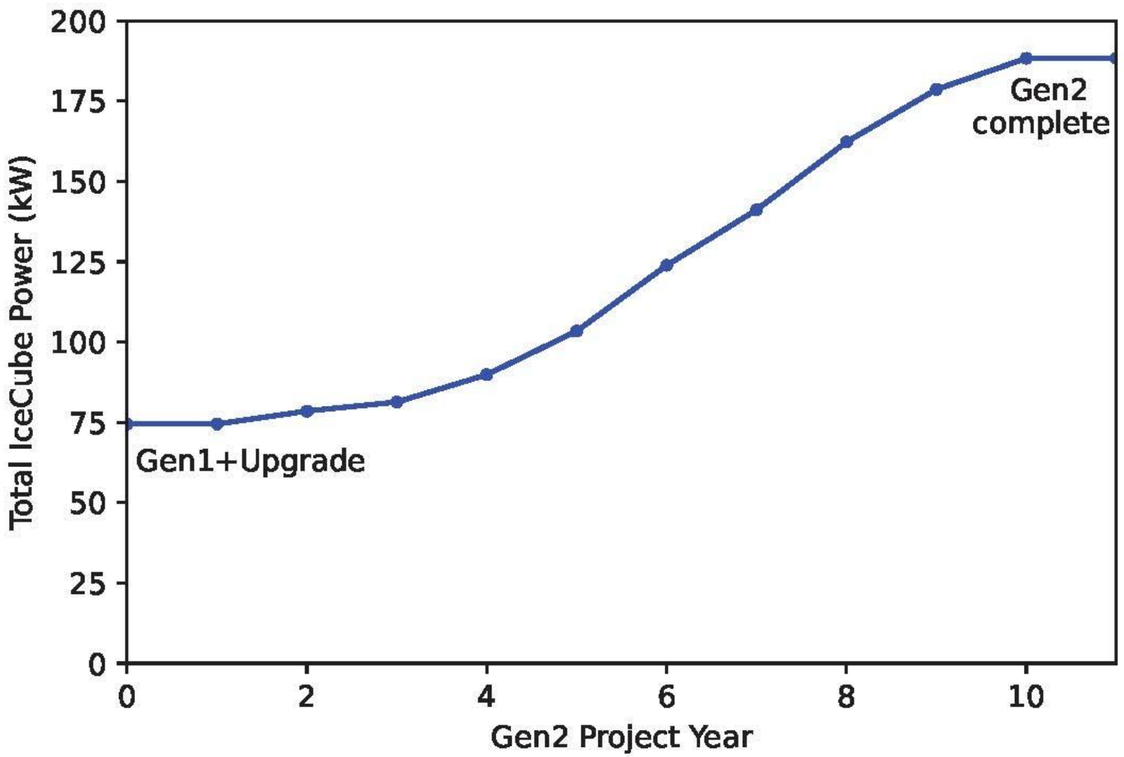
The ship was found last year, in 2022, 3 km deep at the bottom of the ocean. (They all survived. :)



GETTY IMAGES/SPRI

Power Requirements IceCube-Gen2





Planning to work with station on power needs: Investigating the use of the microturbines we will be using to power the drill; renewables → substantial reduction in power needs possible

Logistical Support: Requirements (total)

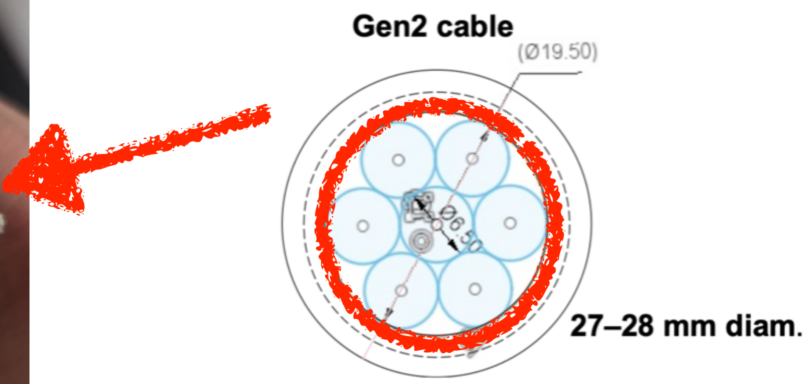
Support requirements are well understood.

	IceCube-Gen2		"Gen1"
South Pole Field Season	**Total**	**Average/year**	IceCube 1 Average
Cargo Weight [1000 lbs]	**3540**	**354**	similar
LC130 Cargo Flights	**69**	**7**	≈45
Population [beds]		**60**	≈50
Fuel [1000 gallons]	**918**	**92**	82

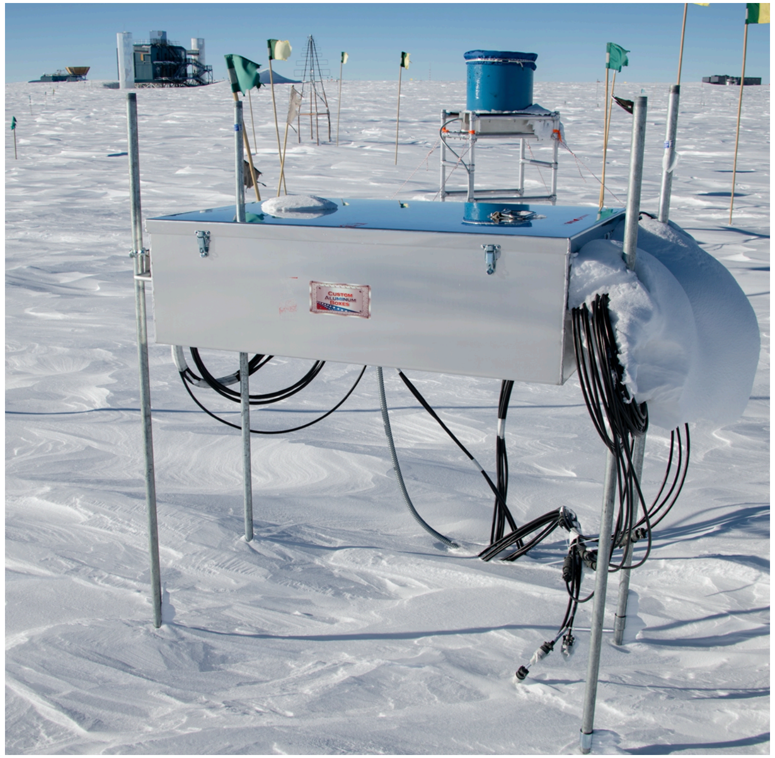
Absolute numbers **comparable to IceCube**.
Only 15 to 20% of flights needed compared to IceCube → most cargo via Overland Traverse

Data acquisition and cables

IceCube Upgrade cable.



Gen2 Fieldhub

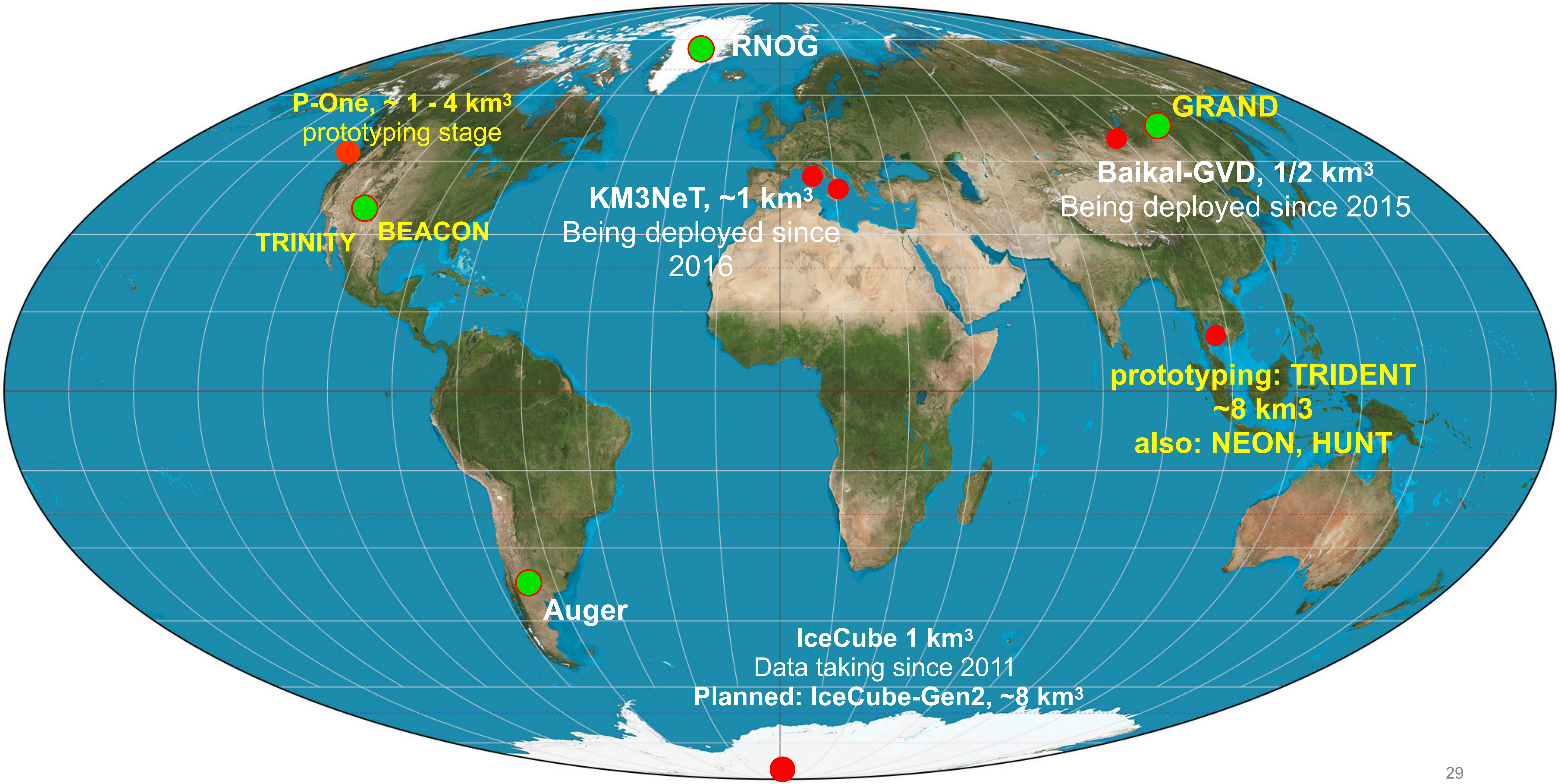


IceCube: 2 DOMs/wire pair
Upgrade: 3 DOMs / wire pair
IceCube-Gen2: 6 Gen2-DOMs/wire pair (=18 x photo detection/wire pair)

This is possible due to a change in DAQ/trigger architecture:

Gen2 will not send all noise hits to the top.

The Global Neutrino Telescope Landscape



Neutrino telescopes at various stages

IceCube 1KM3 in operation since 2011.

New 10km^3 scale detectors proposed: Gen2 + two in China

(proposed) Detector	Country (host)	Instr. Volume /km^3	No. of Modules (size*)	Status (construction completion)
IceCube	USA, Pole	1	5000 (1=ref)	2011 completed
Baikal GVD	Russia	~0.4	5184 (1)	60%
KM3NeT ARCA	EU, Mediterranean	~1	4140 (3,p)	12%
P-ONE	Canada	1 (cluster volume) 3 (envelope vol.)	1400 (3,p)	prototype
NEON	China	1	TBD	R&D
IceCube Gen2	USA	8	9600 (4,p)	design
TRIDENT	China	7.5	3600 (3,p)	prototype
HUNT	China	30	55,000 (4)	R&D

*sensor effective area, unit: IceCube sensor = 1, p= pixelized

References: ICRC