

# Path to IceCube-Gen2

Albrecht Karle

Chiba

September, 2019

# On-Ice Activities in the next few years

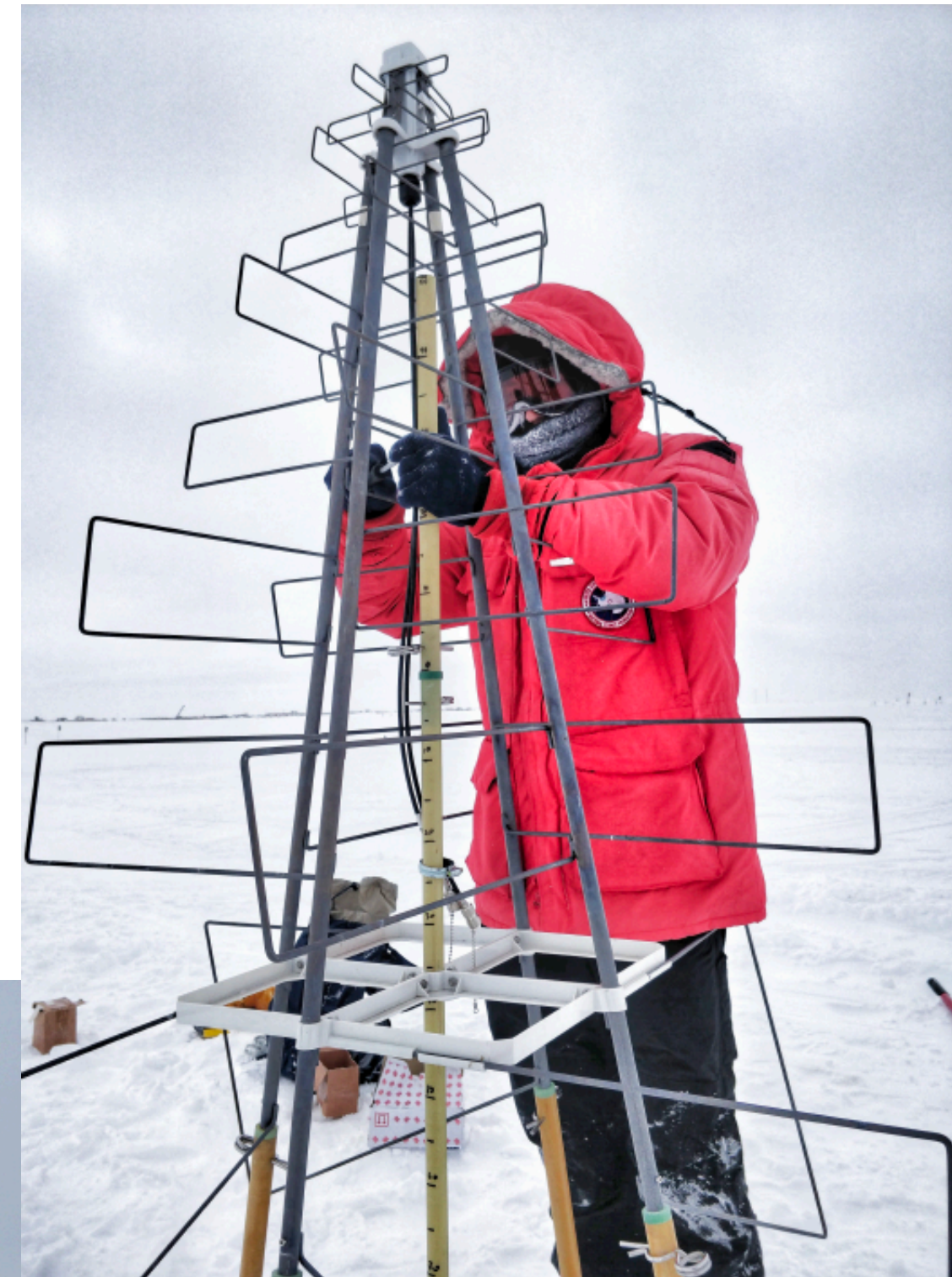
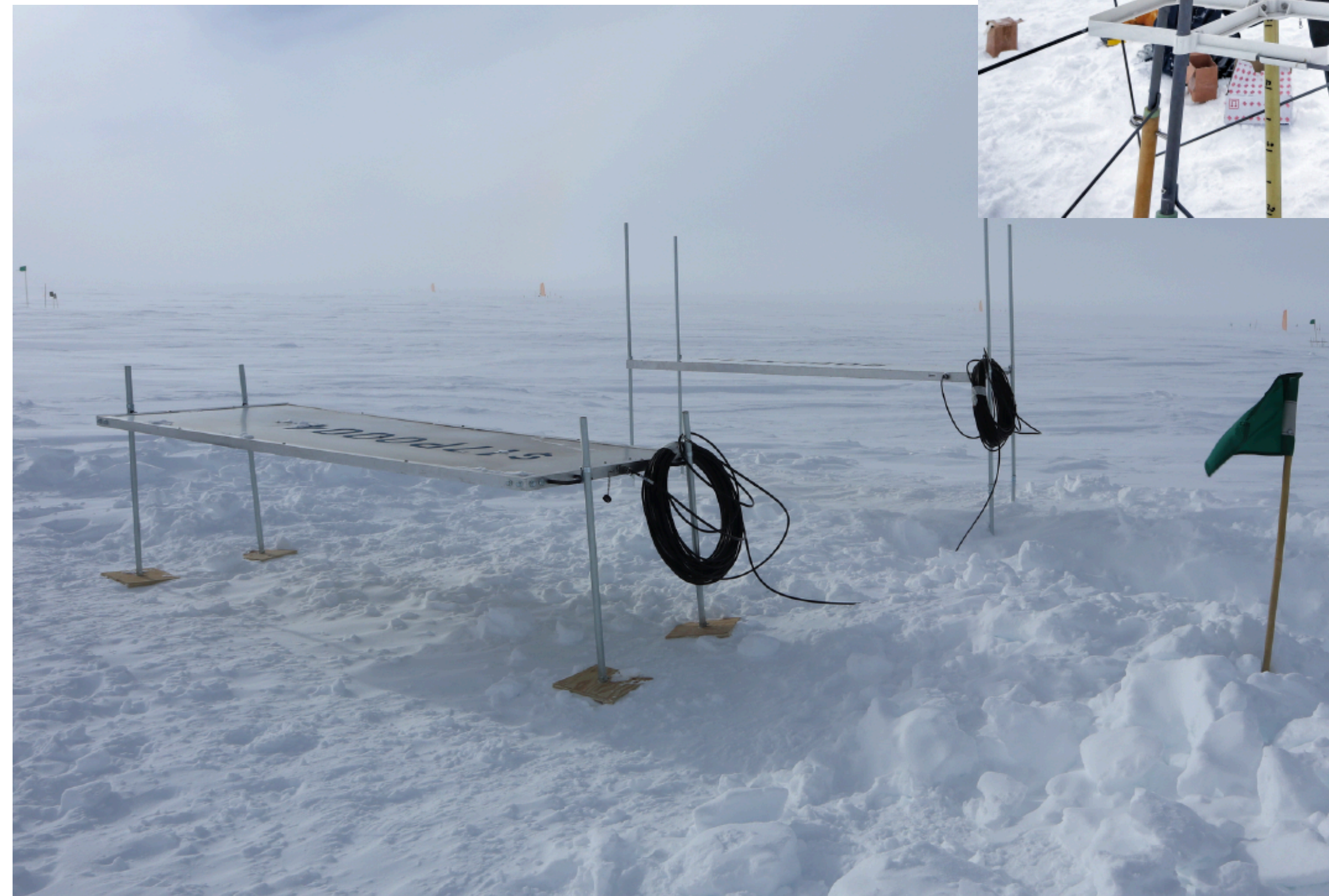
**Icecube Upgrade (separate talk)**

**IceCube Maintenance and Operations**

—> **IceTop maintenance: scintillator upgrade**

**Science:**

- **Enhance neutrino science (by improving understanding backgrounds)**
- **Cosmic ray science**
- **Galactic sources of gamma rays**

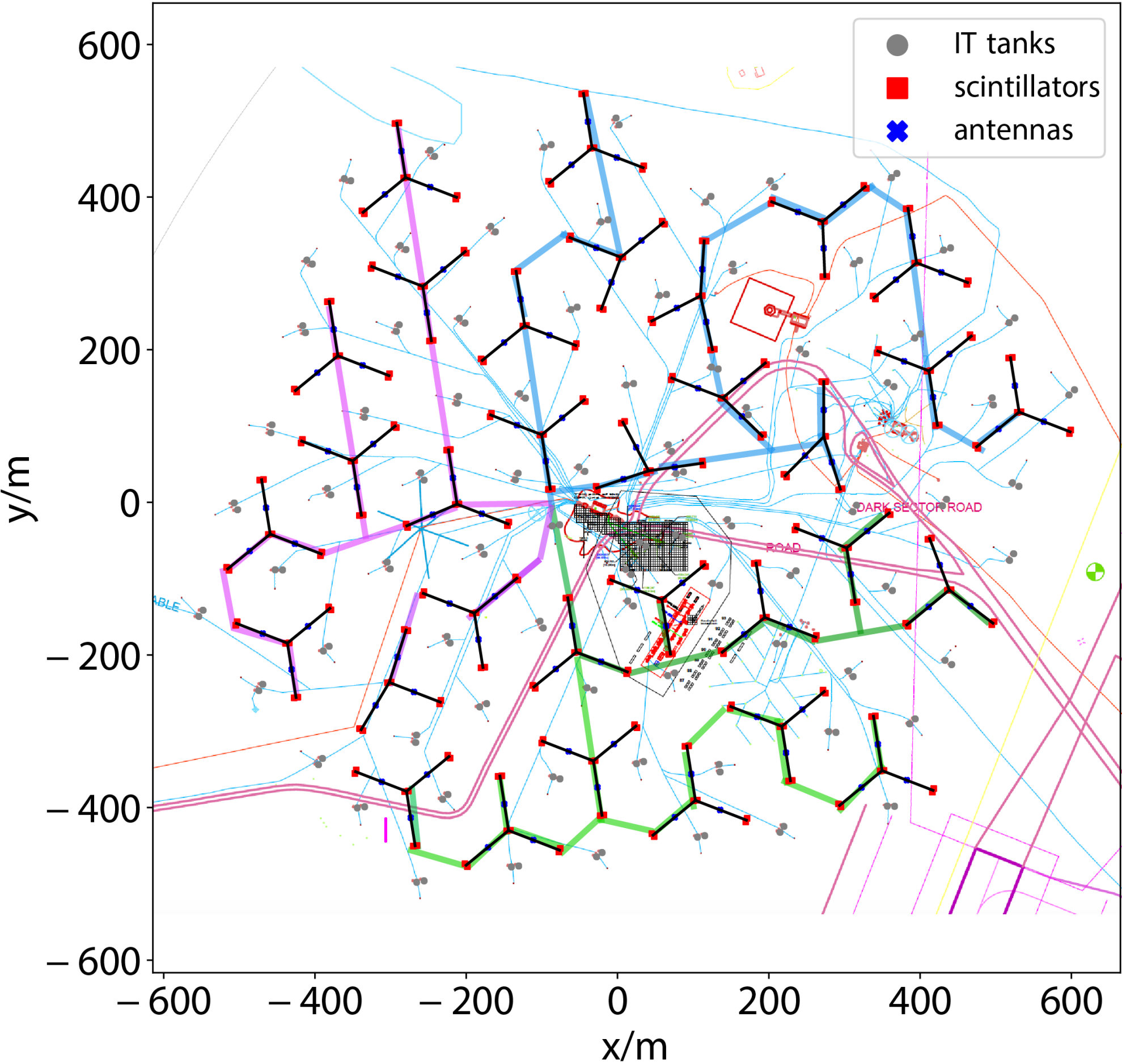


# Scintillators stations for IceTop

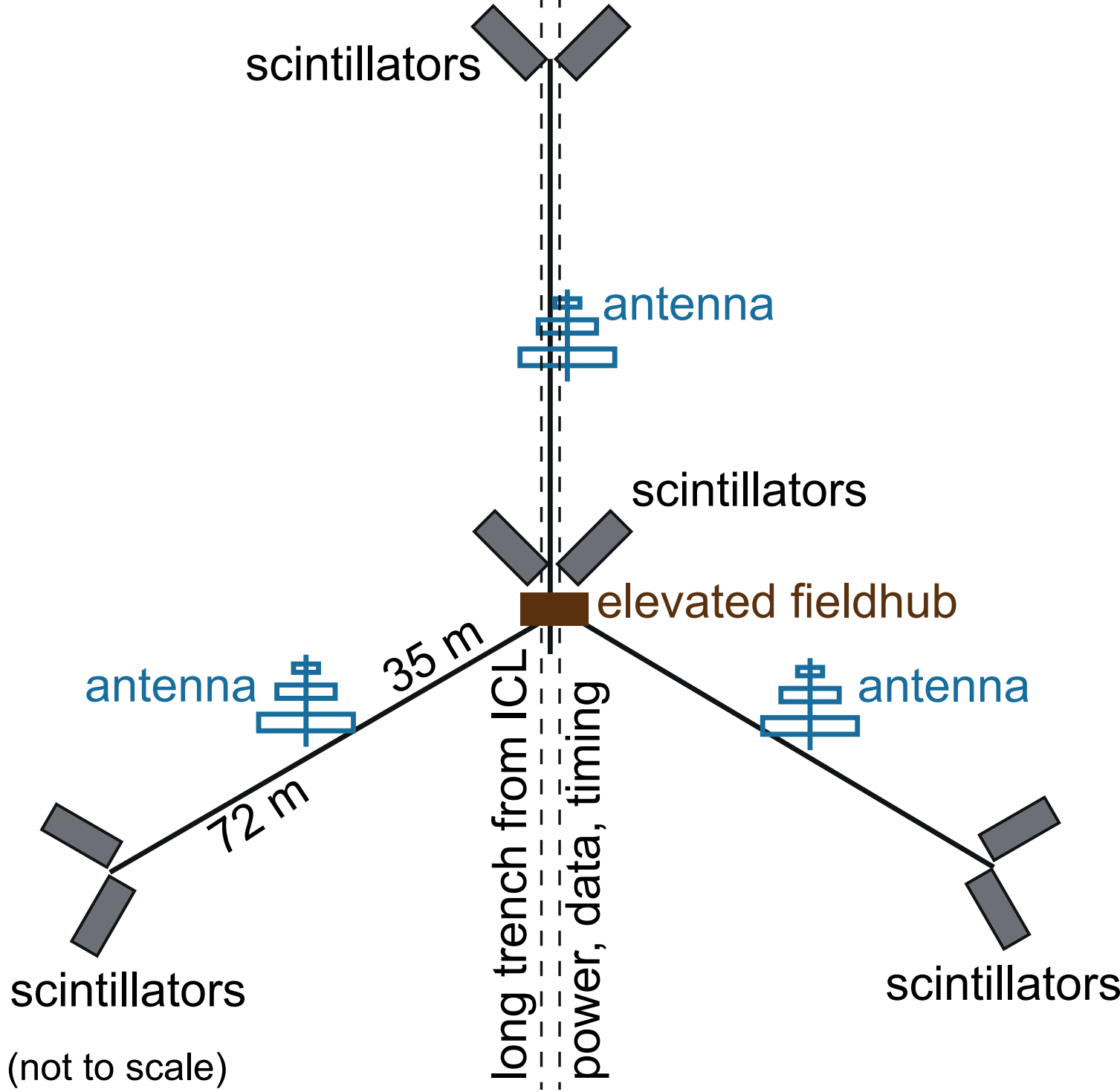
**Schedule:**  
**Deploy 11 stations before upgrade completion**  
**(before 22/23)**  
**The remainder after.**

**Fits inside the nominal M&O on-ice footprint.**  
**Subject to supportability review at NSF.**  
**Document will be submitted.**

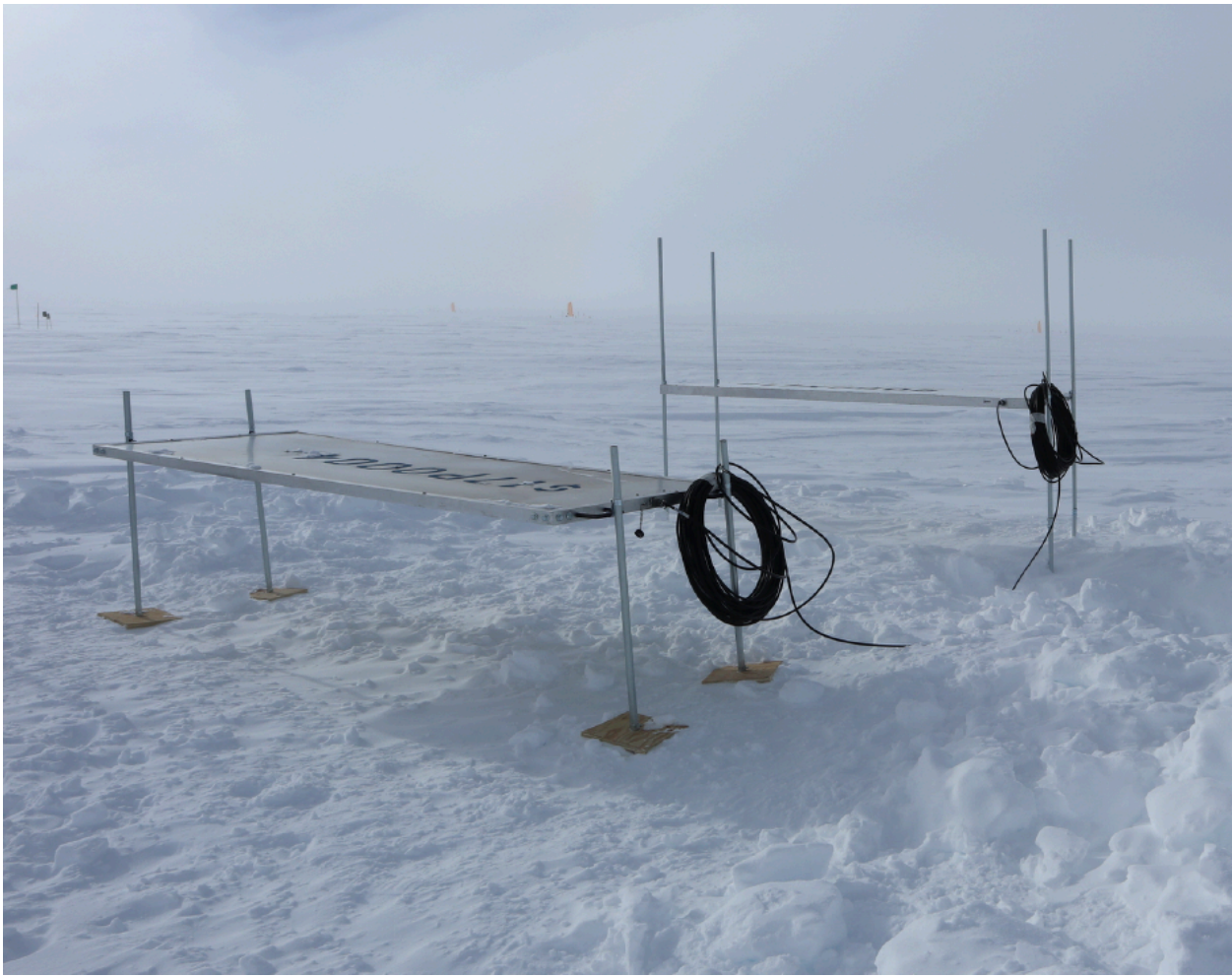
**32 stations**



**Station**



**Scintillator panel**

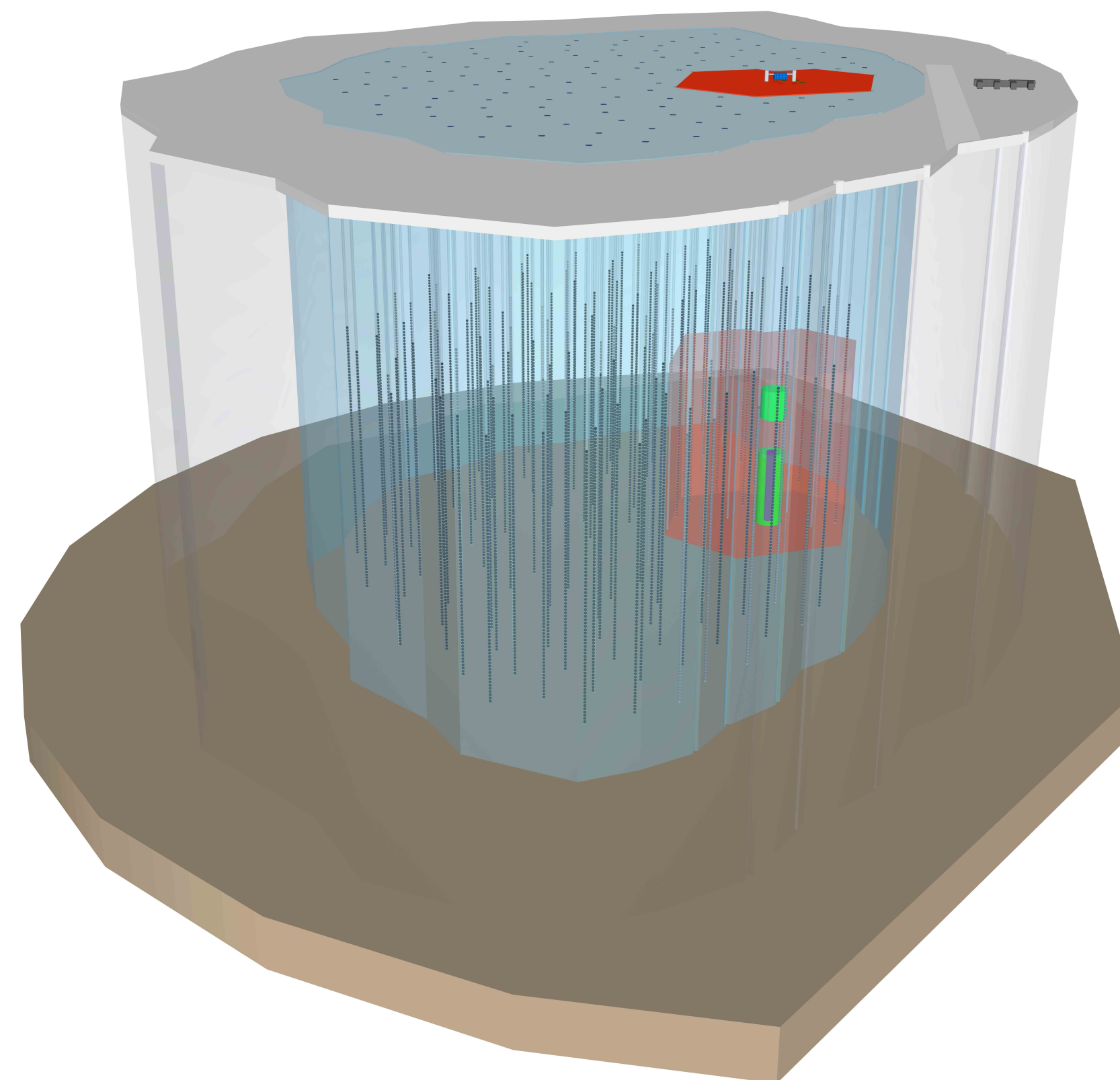


# IceCube-Gen2

The next Generation IceCube: from discovery to astronomy

## Multi-component observatory:

- IceCube-Gen2 High-Energy Array  
(associated cosmic ray array at surface)
- Sub-surface  $\sim 500 \text{ km}^2$  radio array (not shown)



Artist conception  
Here: 120 strings at 300 m spacing

# IceCube-Gen2 white papers

- Three 10-pagers for decadal survey (submitted in March and July)
- 2 x Science
- 1 x Instrument

<https://arxiv.org/abs/1907.12526>

The IceCube-Gen2 Collaboration

## Neutrino astronomy with the next-generation IceCube Neutrino Observatory

**Abstract**

The past decade has seen the rapid emergence of cosmic neutrinos as a new messenger to explore the most extreme environments of the universe. The discovery measurement of cosmic neutrinos, announced by IceCube in 2013, has opened a new window on astrophysics that holds the potential to answer fundamental questions associated with the high-energy universe, including: what are the sources in the PeV sky and how do they drive particle acceleration; where are cosmic rays of extreme energies produced, and on which paths do they propagate through the universe; are there signatures of new physics at TeV–PeV energies and above? The planned advancements in neutrino telescope arrays in the next decade, in conjunction with continued progress in broad multimessenger astrophysics, promise to see the cosmic neutrino field move from the discovery era to the precision era and to a survey of the sources in the neutrino sky. The planned detector upgrades to the IceCube Neutrino Observatory, culminating in IceCube-Gen2 — an envisaged \$400M facility with anticipated operation in the next decade described in this white paper — are the cornerstone that will drive the evolution of neutrino astrophysics measurements.

Contact: [analysis@icecube.wisc.edu](mailto:analysis@icecube.wisc.edu)

July 2019

<https://arxiv.org/abs/1903.04334>

Astro2020 Science White Paper

## Astrophysics Uniquely Enabled by Observations of High-Energy Cosmic Neutrinos

Thematic Area: Multi-Messenger Astronomy and Astrophysics

Markus Ackermann, *Deutsches Elektronen-Synchrotron (DESY) Zeuthen*  
 Markus Ahlers<sup>\*</sup>, *Niels Bohr Institute, University of Copenhagen*  
 Luis Anchordoqui<sup>†</sup>, *City University of New York*  
 Mauricio Bustamante<sup>‡</sup>, *Niels Bohr Institute, University of Copenhagen*  
 Amy Connolly, *The Ohio State University*  
 Cosmin Deaconu, *University of Chicago*  
 Darren Grant<sup>§</sup>, *Michigan State University*  
 Peter Gorham, *University of Hawaii, Manoa*  
 Francis Halzen, *University of Wisconsin, Madison*  
 Albrecht Karle<sup>¶</sup>, *University of Wisconsin, Madison*  
 Kumiko Kotera, *Institut d'Astrophysique de Paris*  
 Marek Kowalski, *Deutsches Elektronen-Synchrotron (DESY) Zeuthen*  
 Miguel A. Mostafa, *Pennsylvania State University*  
 Kohta Murase<sup>‡</sup>, *Pennsylvania State University*  
 Anna Nelles<sup>§</sup>, *Deutsches Elektronen-Synchrotron (DESY) Zeuthen*  
 Angela Olinto, *University of Chicago*  
 Andres Romero-Wolf<sup>¶</sup>, *Jet Propulsion Laboratory, California Institute of Technology*  
 Abigail Vieregg<sup>¶</sup>, *University of Chicago*  
 Stephanie Wissel<sup>¶</sup>, *California Polytechnic State University*

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<sup>†</sup>luis.anchordoqui@ciupcu.wisc.edu, +1 608 890 0542  
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<sup>§</sup>anna.nelles@desy.de, +49 33762 77399  
<sup>¶</sup>andrew.romero-wolf@jpl.nasa.gov, +1 818 354 0058  
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March 2019

<https://arxiv.org/abs/1903.04333>

Astro2020 Science White Paper

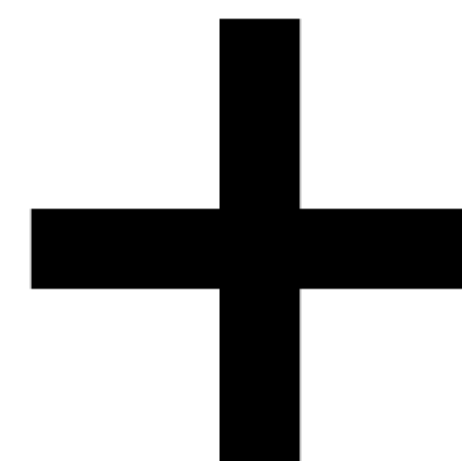
## Fundamental Physics with High-Energy Cosmic Neutrinos

Thematic Area: Cosmology and Fundamental Physics

Markus Ackermann, *Deutsches Elektronen-Synchrotron (DESY) Zeuthen*  
 Markus Ahlers<sup>\*</sup>, *Niels Bohr Institute, University of Copenhagen*  
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<sup>‡</sup>dr@msu.edu, +1 517 884 2567  
<sup>§</sup>andrew.romero-wolf@jpl.nasa.gov, +1 818 354 0058  
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<sup>¶</sup>wissel@calpoly.edu, +1 805 756 7375

March 2019



**A more extensive white paper for the community** (in preparation of possible invitation by NSF to submit a proposal for an MREFC)

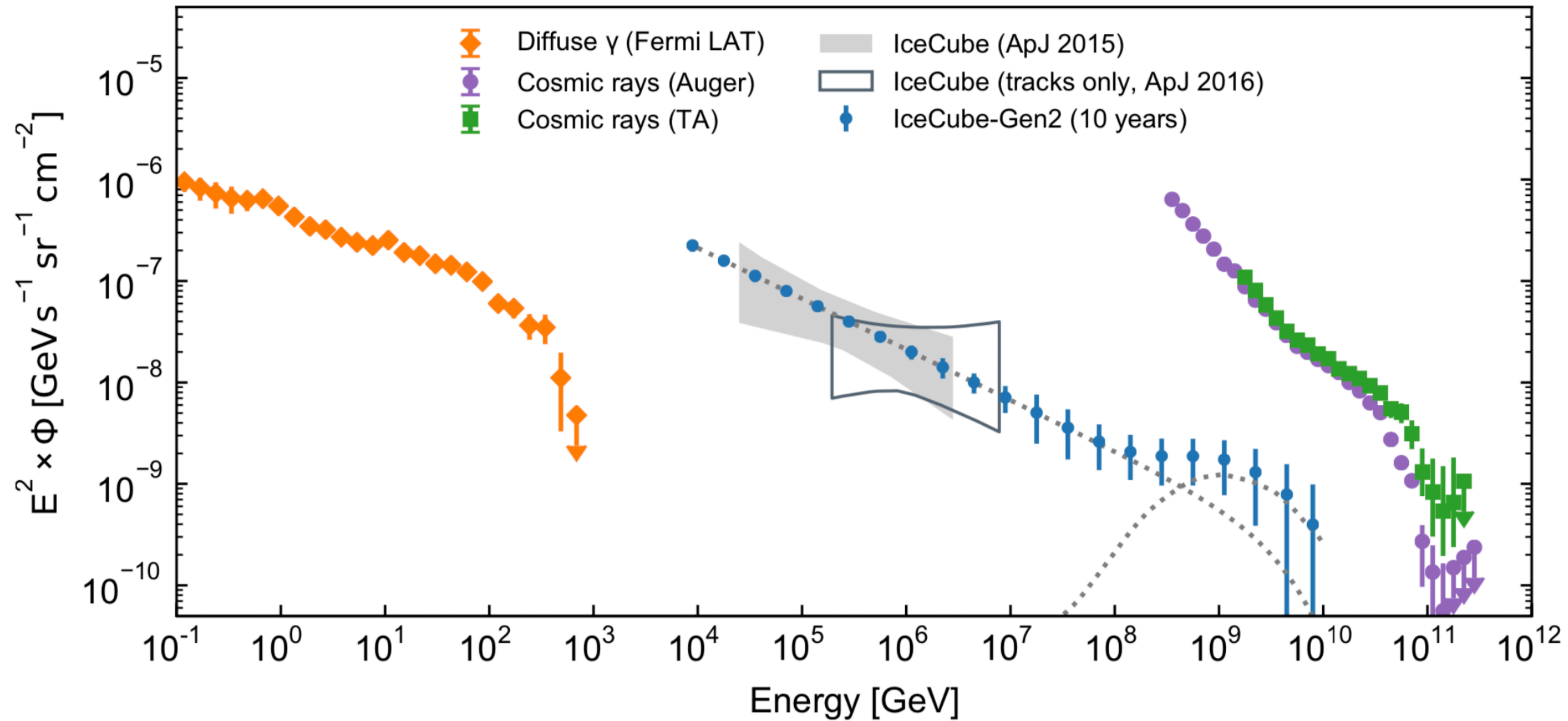
IceCube-Gen2: The Window to the Extreme Universe

The IceCube-Gen2 Collaboration

### Contents

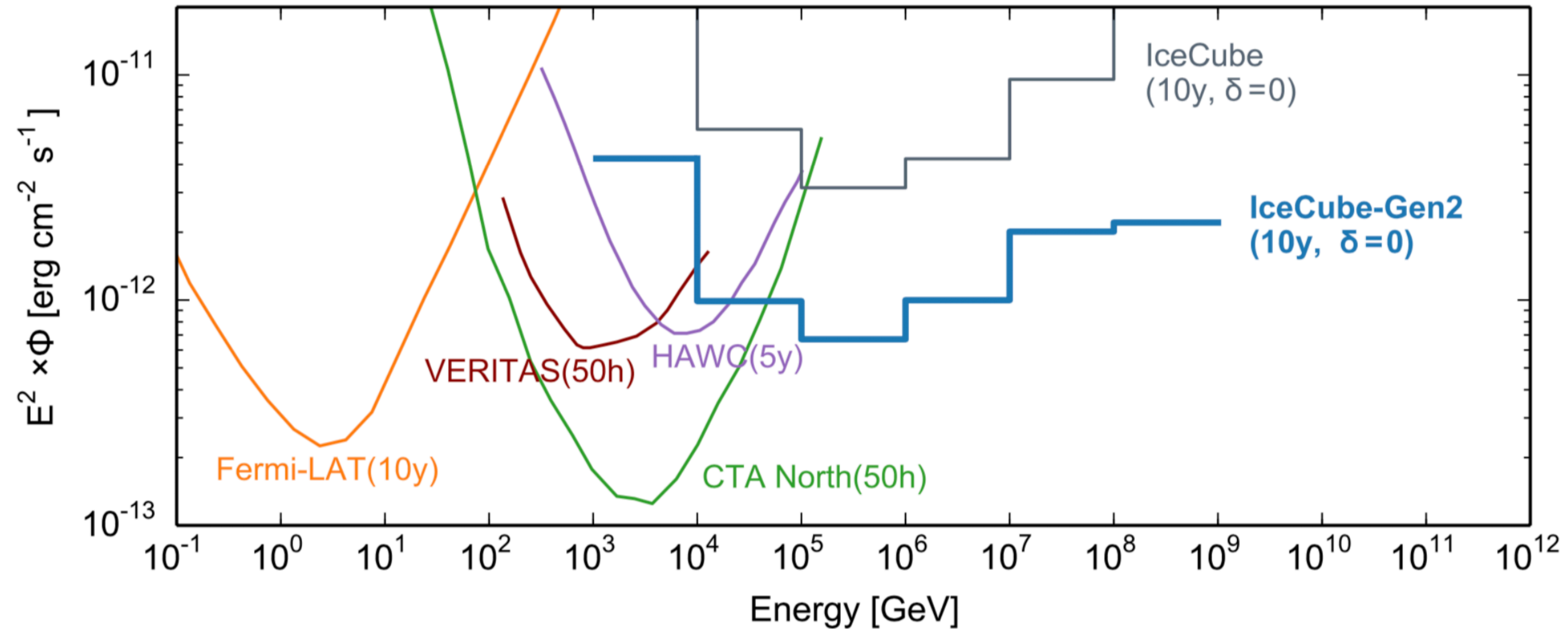
- 1 Introduction**
- 2 IceCube and the discovery of high energy cosmic neutrinos**
  - 2.1 Identifying the sources of high-energy neutrinos . . . . .
  - 2.2 The energy spectrum and flavor composition of cosmic neutrinos . . . . .

# Diffuse neutrino spectrum



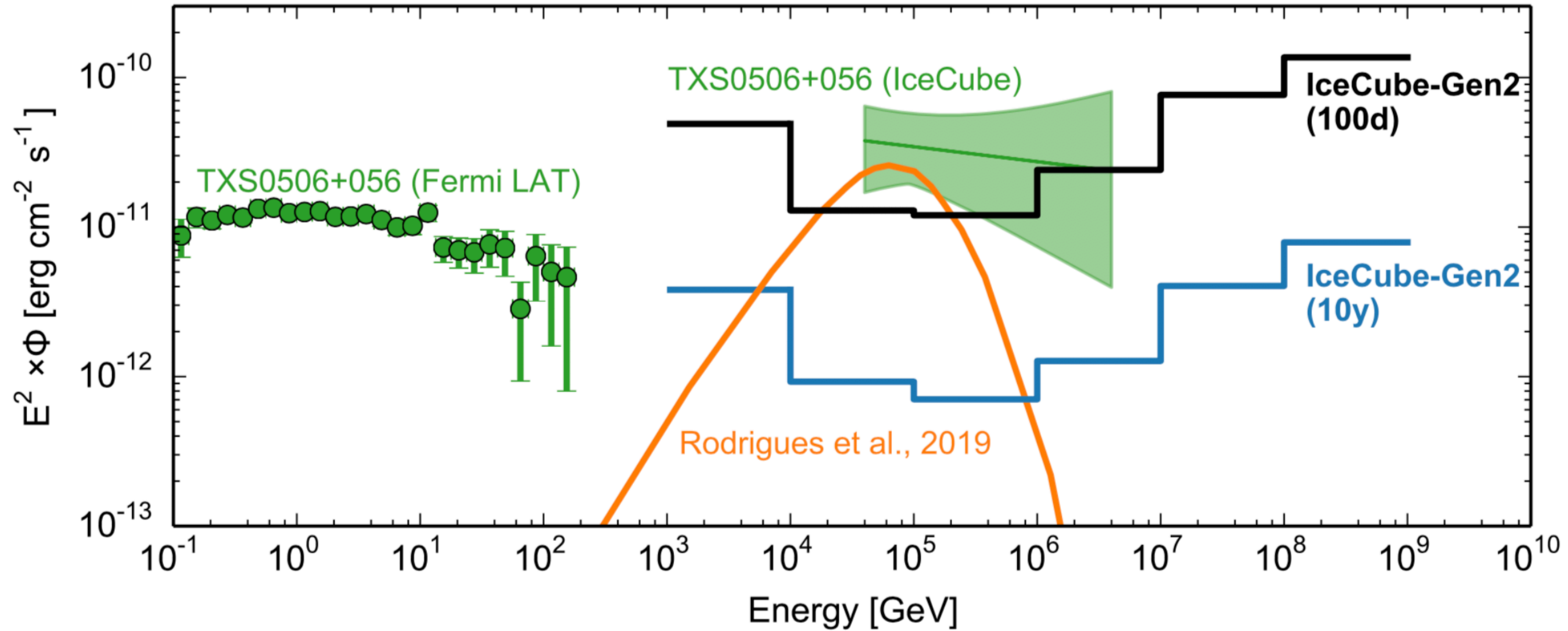
- Visualizing the energy and precision that IceCube-Gen2 can reach.
- Optical + radio array
- Astrophysical and cosmogenic contributions

# Point sources - differential sensitivity



- Comparison of the differential sensitivity to current and future gamma-ray instruments

# Multi-messenger astronomy: Blazars and AGN



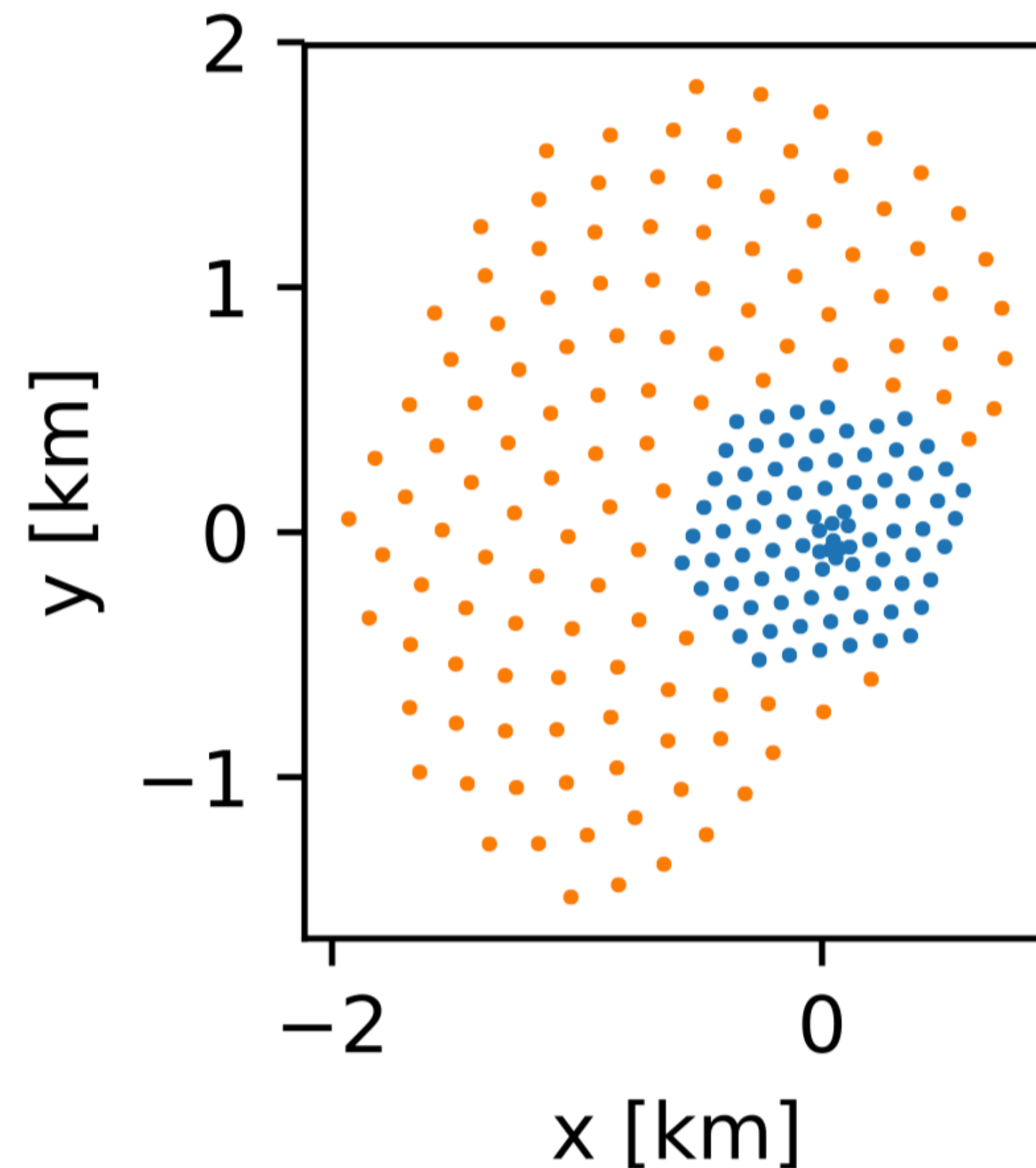
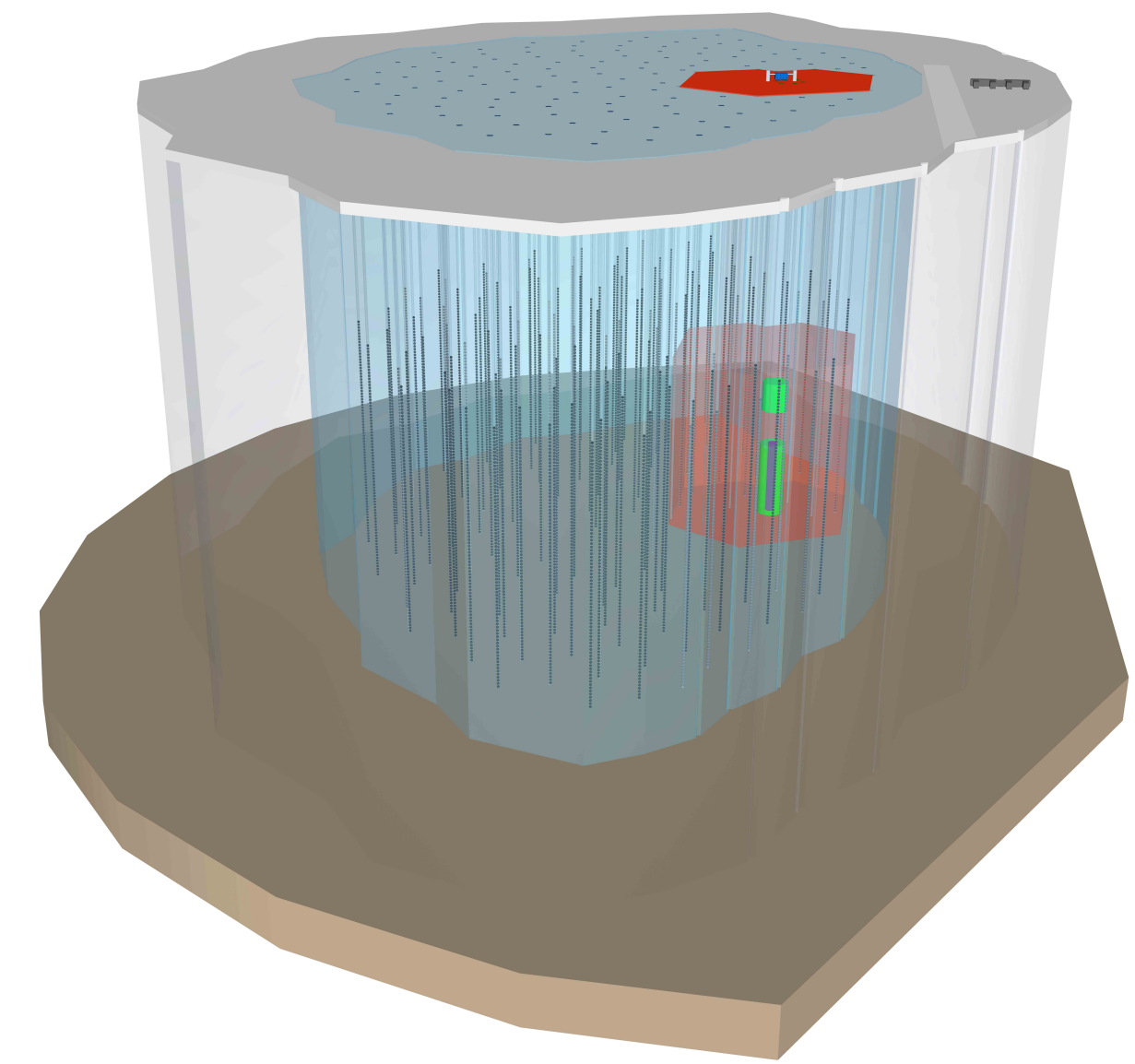
- What is Gen2's sensitivity relative to the signal observed for TXS 0506+056 ?



# The Gen2 optical array

(unchanged)

- 120 strings x 80 DOMs
- DOMs  $\sim 3$  x photodetection of IceCube DOM
- Vertical depth: 1360 m - 2610 m
- “240 m” sunflower
- Instrumented volume:  $7.9 \text{ km}^3$
- Surface area:  $\sim 6.5 \text{ km}^2$

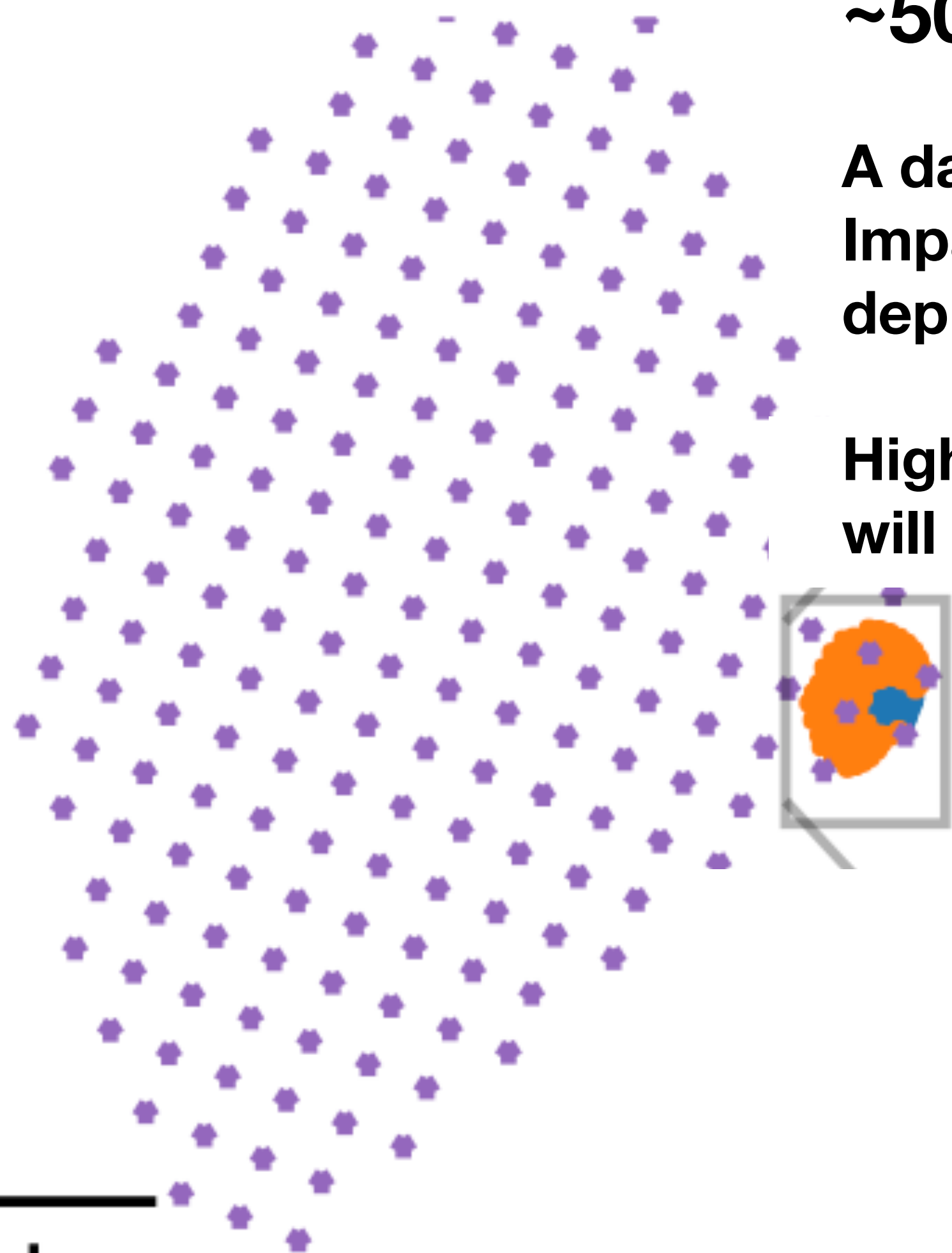


# The Gen2 Radio array

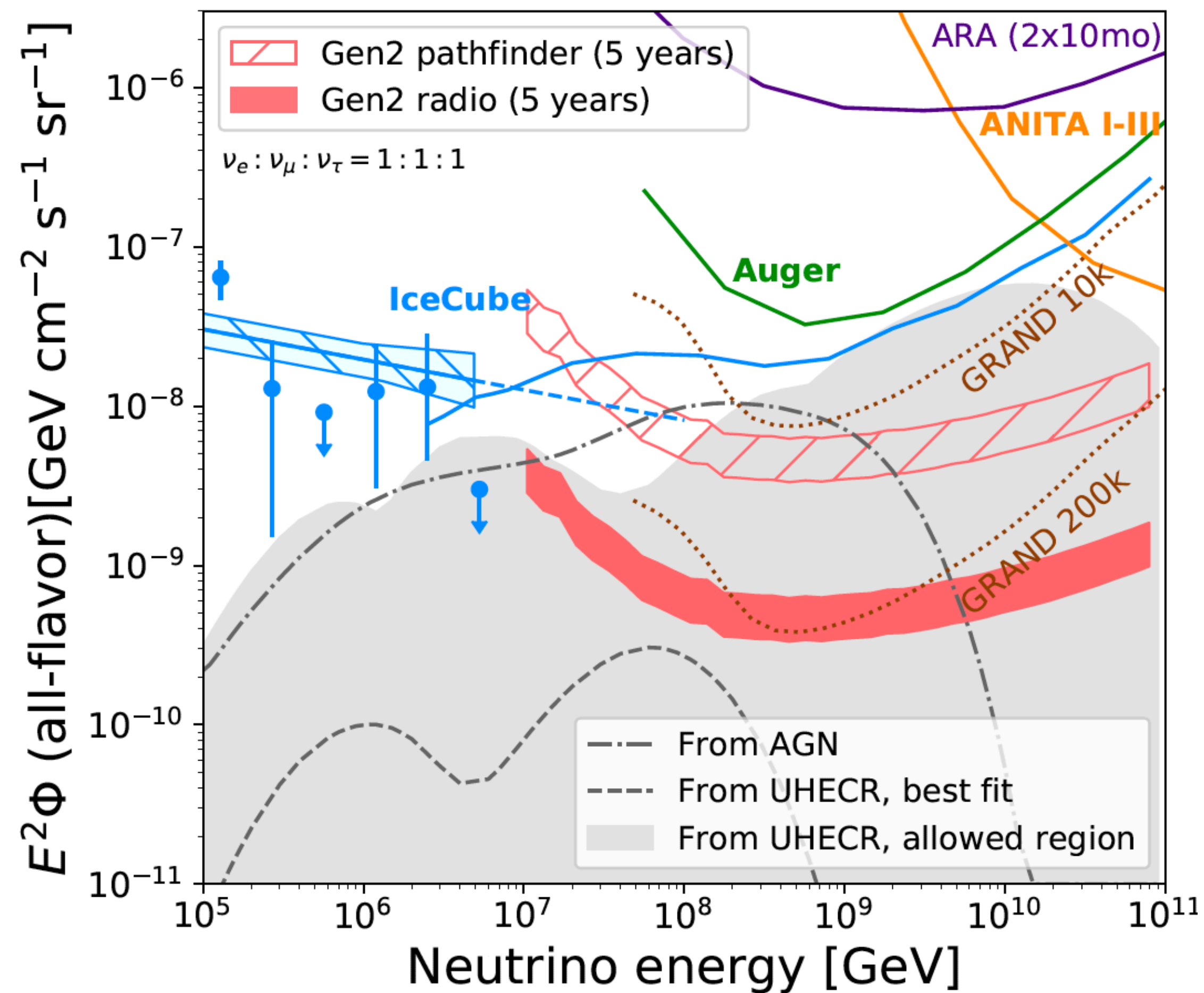
**200 stations**  
**~500 km<sup>2</sup>**

**A daunting scale!**  
**Impact on Gen2**  
**deployment.**

**Highly efficient deployment**  
**will be critical.**



5 km



# The Gen2 Radio array

There is a need for an R&D cycle before Gen2 MREFC.

Groups are developing plans for R&D, including a pathfinder array in Greenland.

Lighter weight approach to station design, no cables, less power.

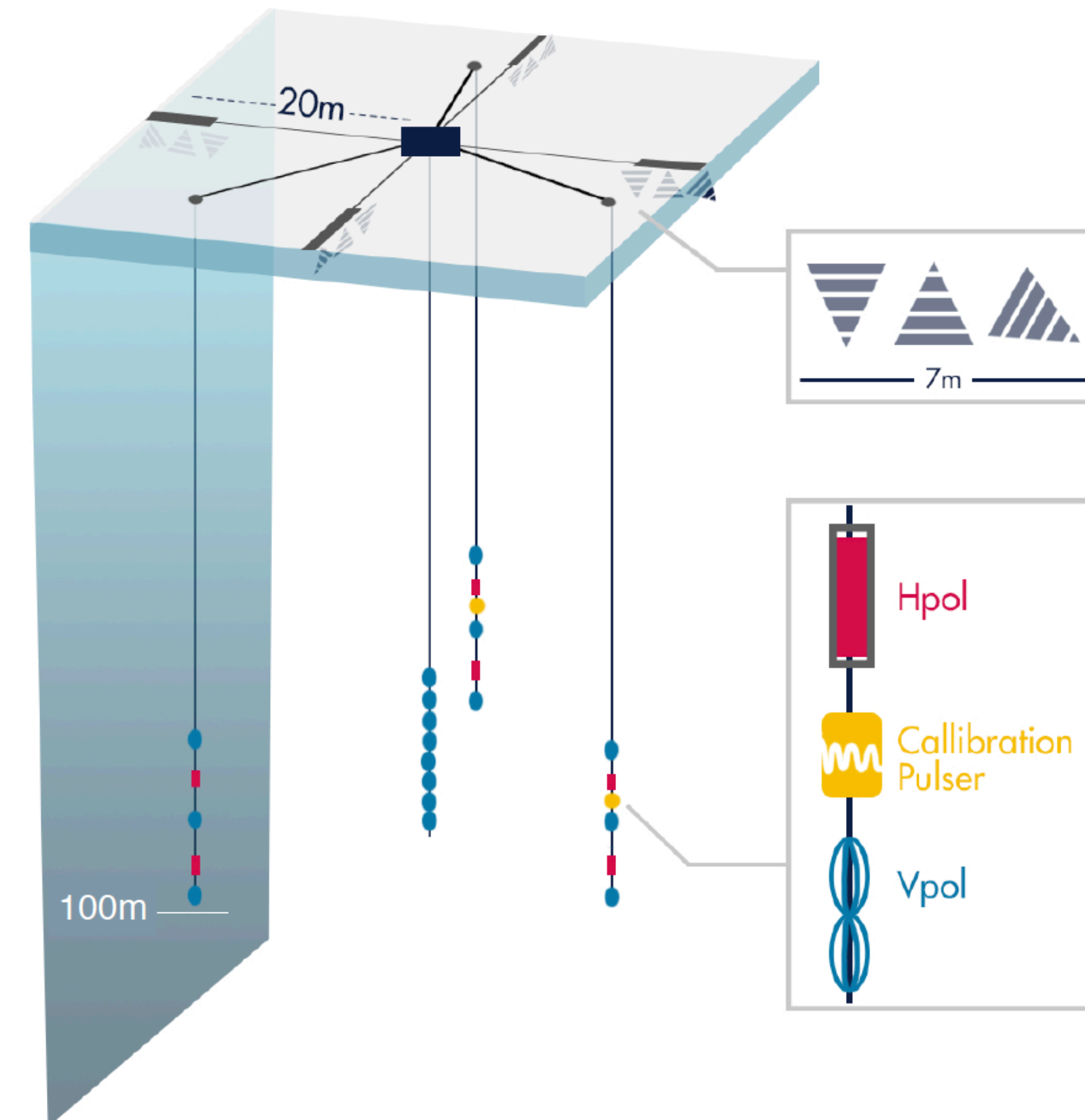
Some R&D effort planned for South Pole, inc. some effort taking advantage of ARA stations and Upgrade.

**Developing a coherent R&D plan for radio detection aimed at Gen2**

**Station design:**

**Development following ARA station 5,  
Further developed by RNO collaboration.  
3 strings plus one phased array trigger, depth  
100 m**

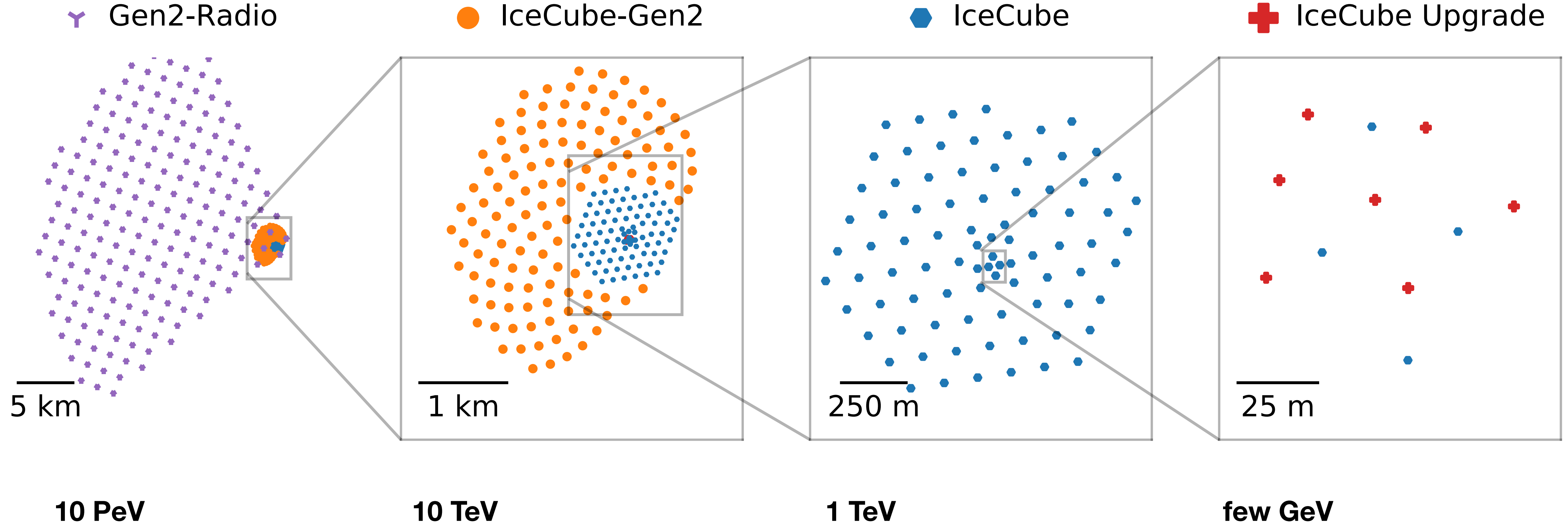
**Surface component  
Autonomous**



<https://arxiv.org/abs/1907.12526>

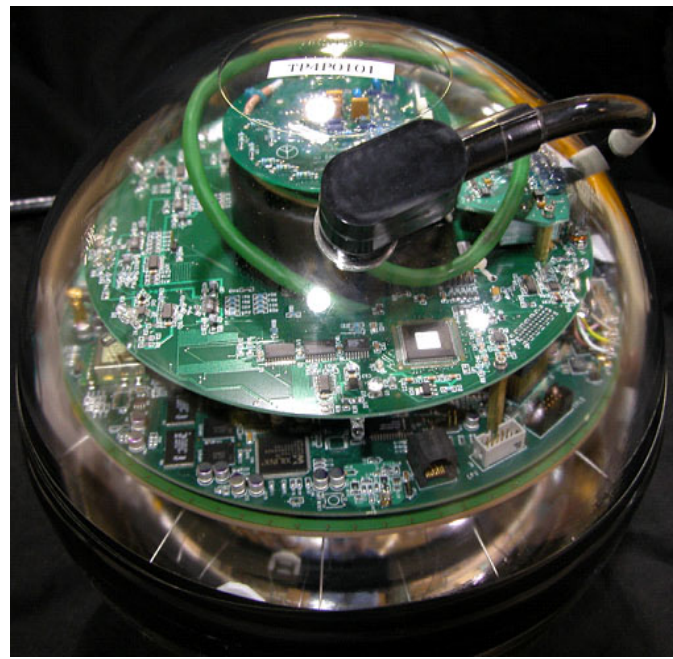
# IceCube Gen2 - scope

IceCube and Gen2 on different scales reflecting different energies



# Sensor design R&D for improved performance

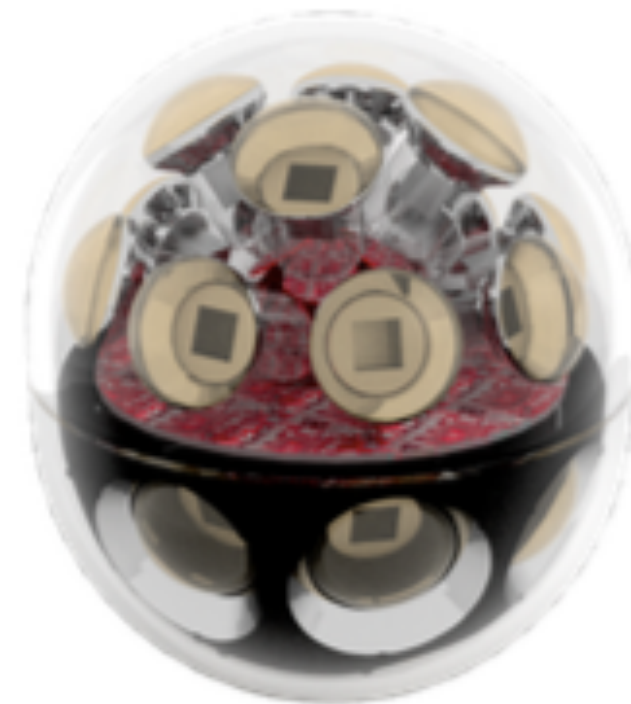
IceCube  
DOM



33 cm

## Upgrade primary sensors

mDOM



36

- Directional information
- More sensitive area per module

D-Egg

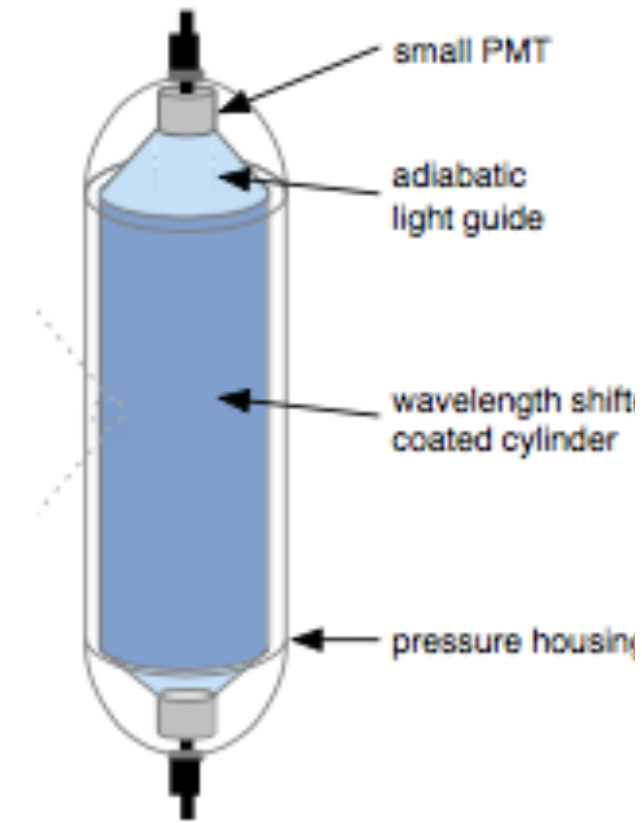


30

- Directional information
- More sensitive area per module
- Smaller geometry

## Smaller diameter

WOM



11

- more sensitive area per \$
- Small diameter
- Lower noise rate

LOM



27

- Small diameter
- Directional info.
- More area per module

FOM



**MDOM and Degg are primary sensors for Upgrade.  
R&D for Gen2 for multi DOM and including other sensor concept.**

# Gen2 - R&D

Optical sensors (previous slide)

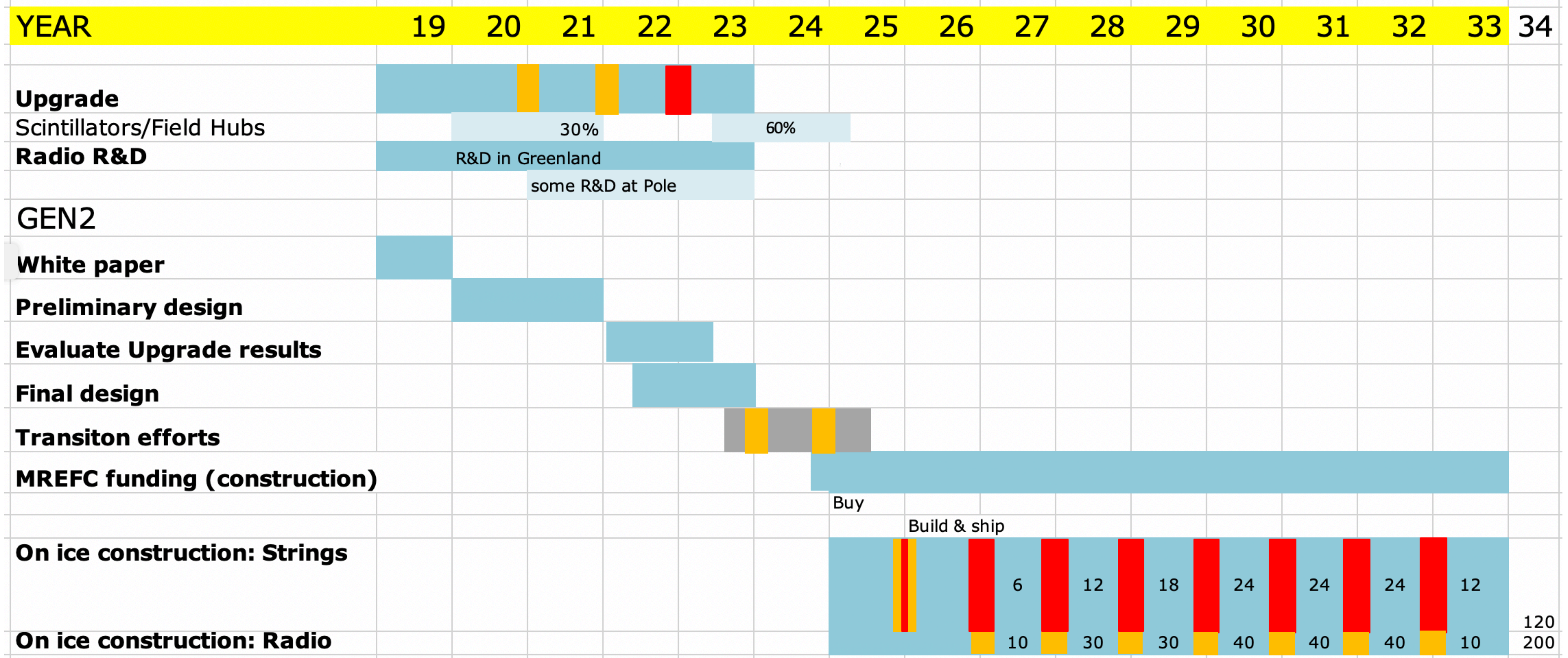
Power and communications architecture: take advantage of changing technology, possible transition to fibers, other ways to optimize communication

Surface cables - switch comms from copper to fiber. Considering deployment of a “field hub” at the top of the string on the ice. (technology partially established in scintillator project).

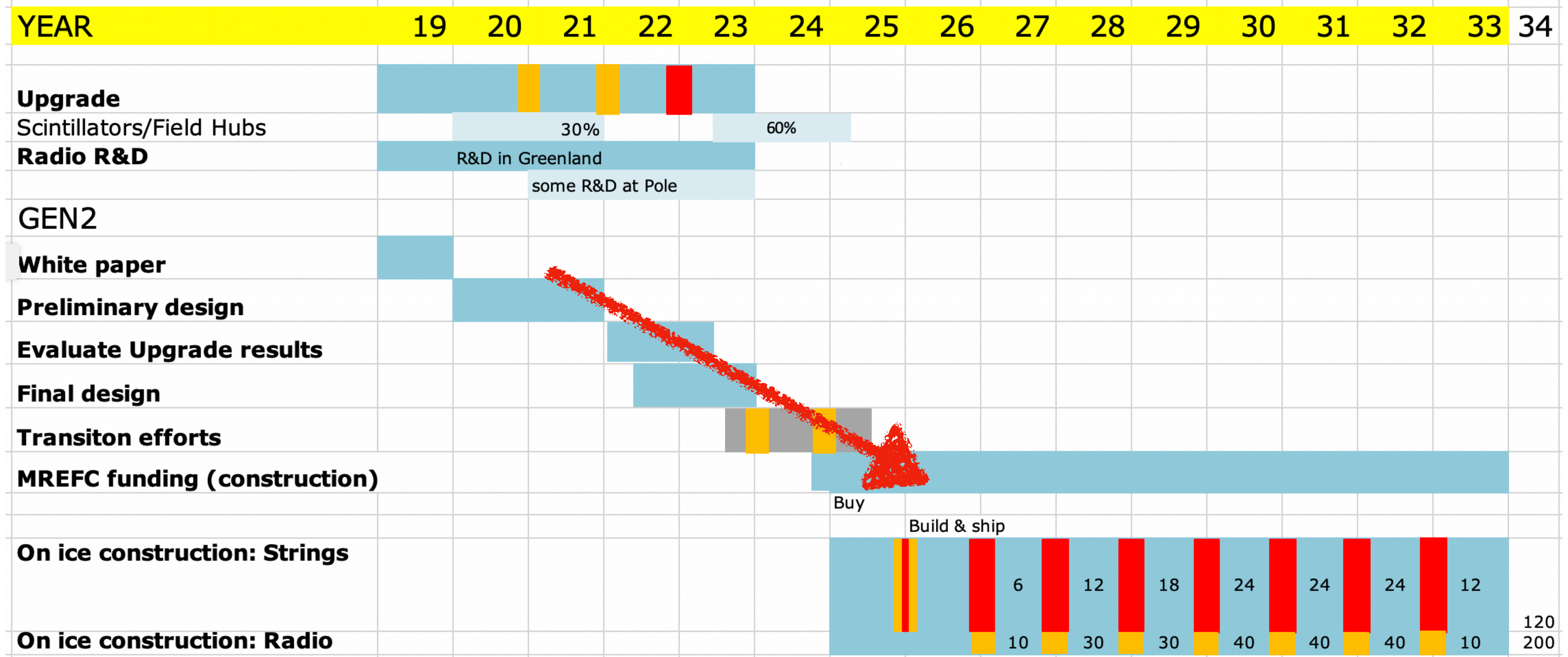
Drill: eg develop design for mobility, more efficient power generators.

Radio detection: advance design for Gen2 scale (low power, no wires, very minimal maintenance).

# Developing schedule baseline for Gen2



# Developing schedule baseline for Gen2



**Transition period needs careful planning to enable a rapid and effective ramp-up of construction. There will be support needs.**



# Summary

Progress with definition of scope.

Gen2 scope now includes radio, coherent Gen2 oriented approach important

Smooth path forward on Upgrade is important.

White papers posted, longer version available soon.

In parallel, ramp up R&D and planning for Gen2. Increasing coordination of effort.

The launch of a Gen2 MREFC by the end of 2023 or early 2024 is a real possibility.

Watch address by NSF director France A. Córdova to the ICRC in Madison this summer, where she notes the Upgrade and makes reference to plans for IceCube Generation 2:

**<https://www.youtube.com/watch?v=JhjHnv526fE>**



Time: 1:04