The IceCube Upgrade

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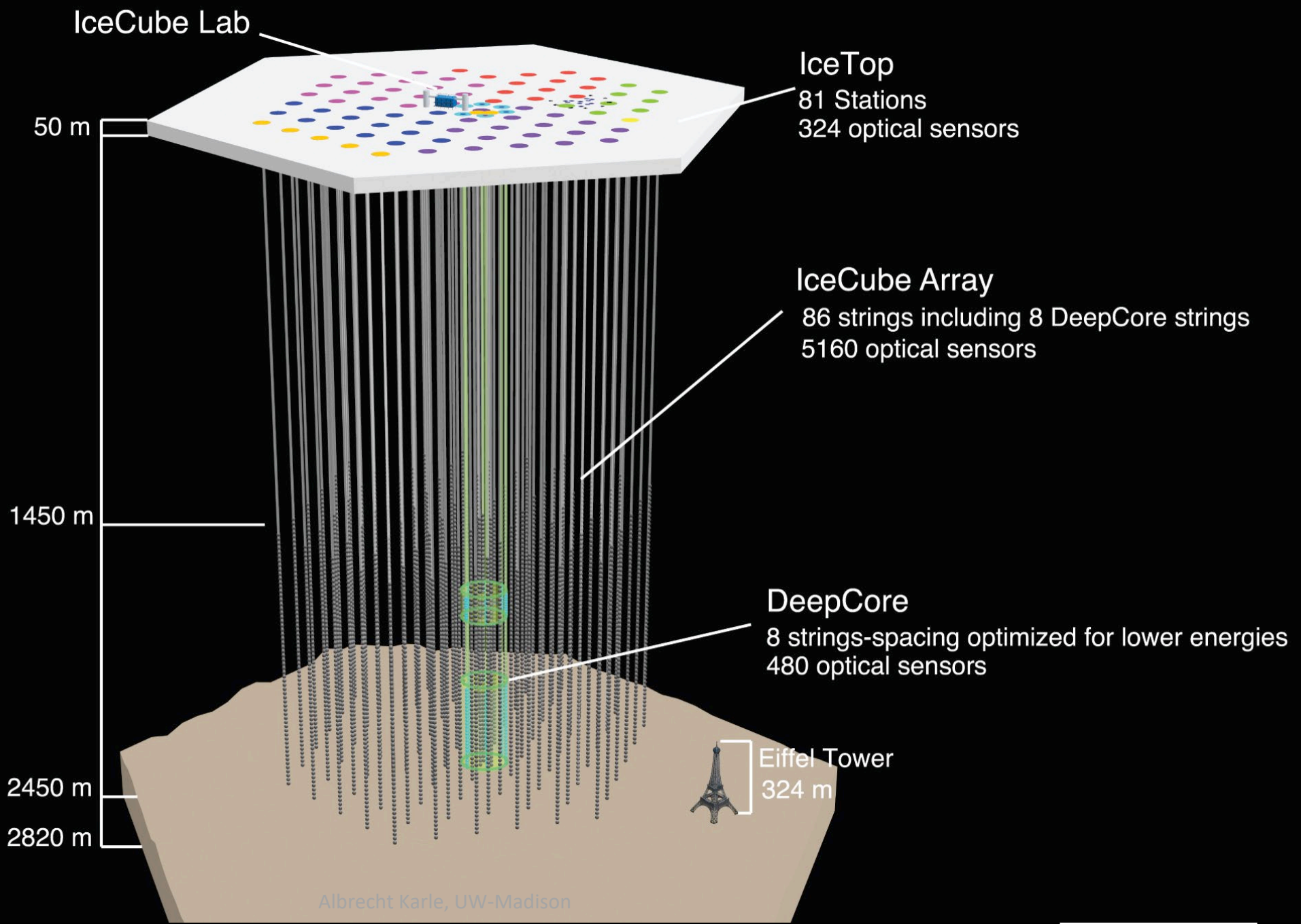
Credit: Yuya Makino, IceCube/NSF

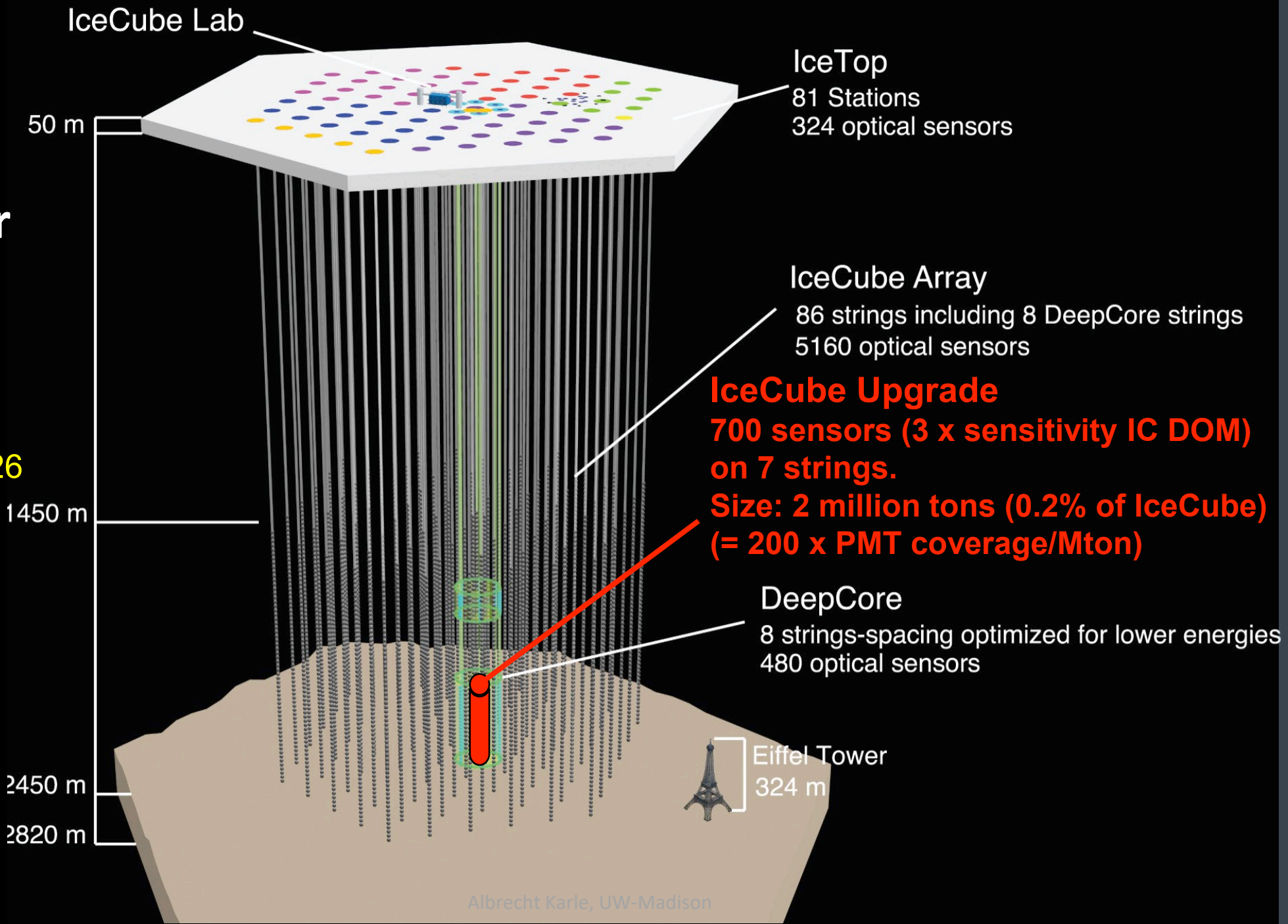
The IceCube Neutrino Observatory

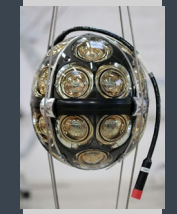
1 cubic kilometer of ice instrumented with 5000 PMTs.

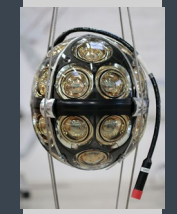


The IceCube Neutrino Observatory + IceCube Upgrade

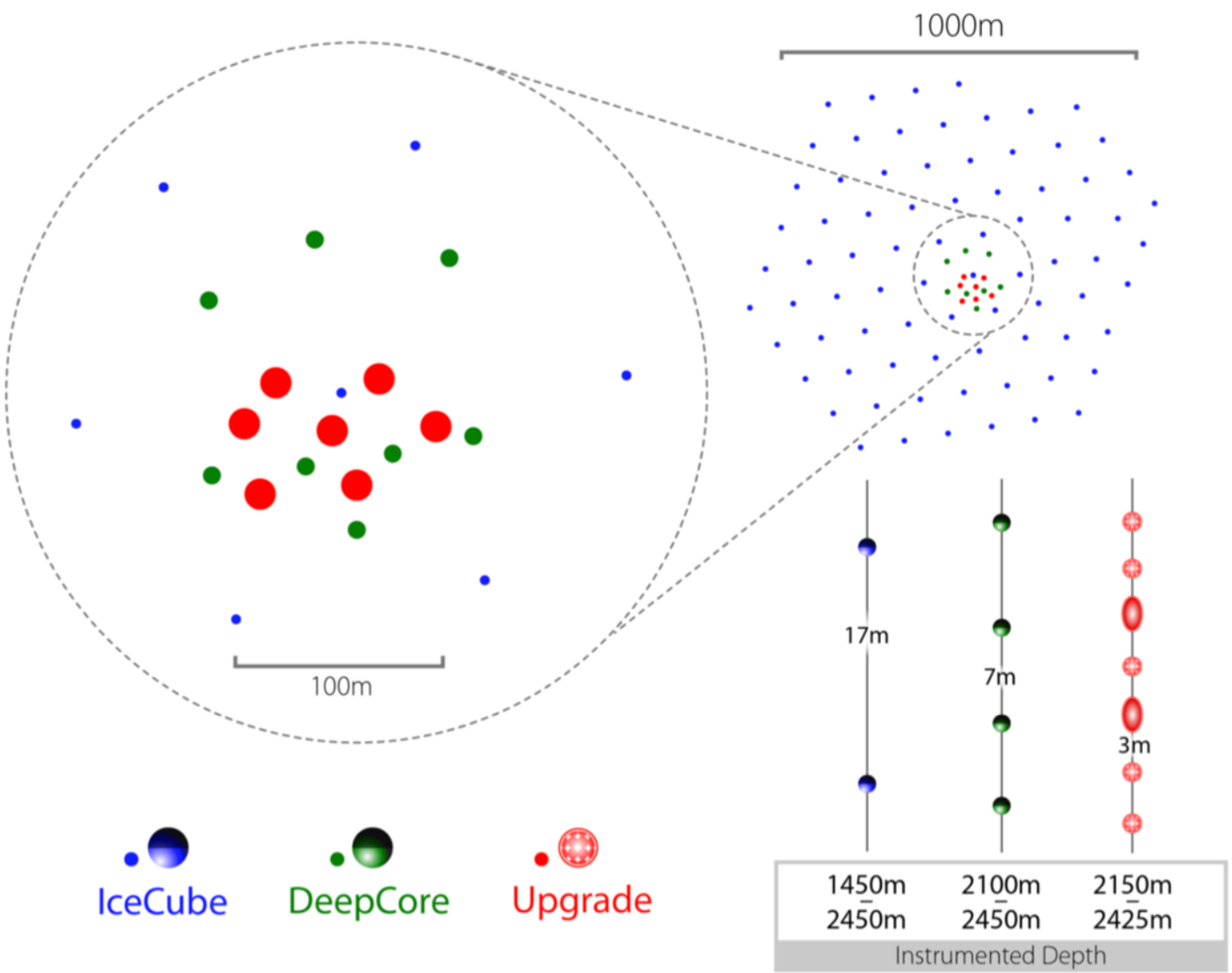
Deploy in 2025/26







Phase 1: The IceCube Upgrade



Scope:

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

Objective:

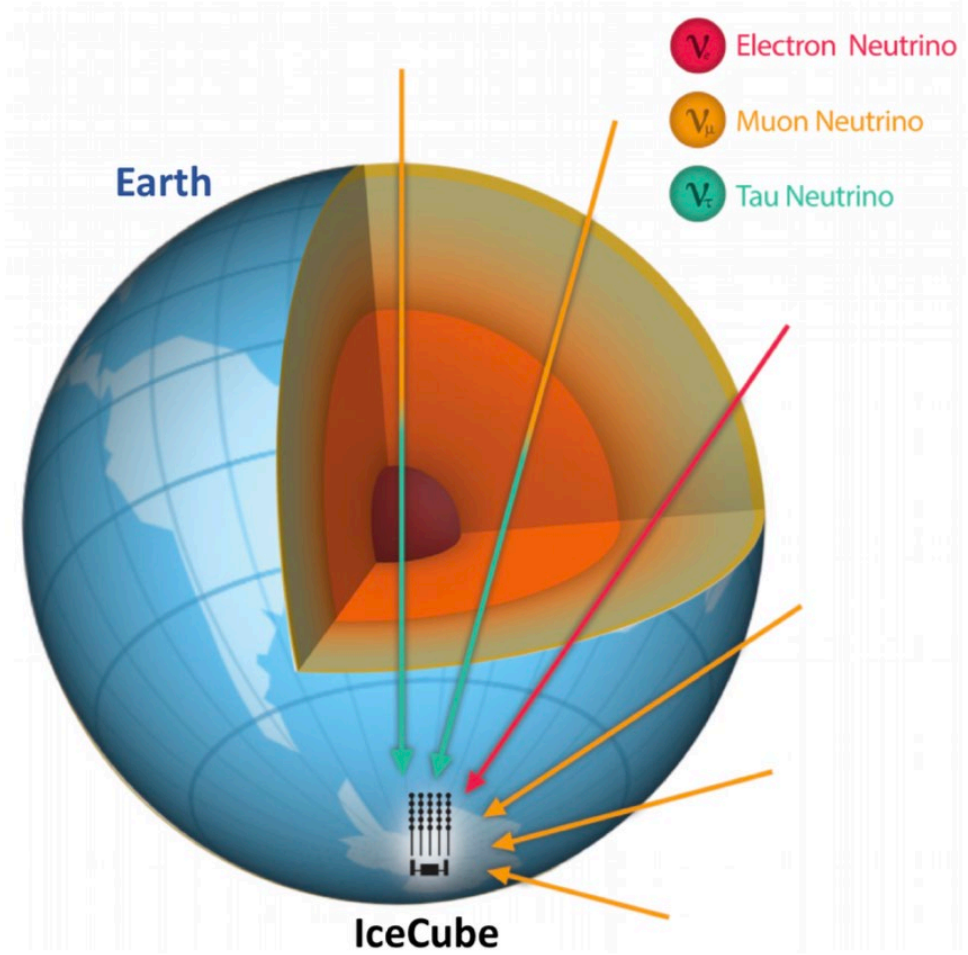
- Precision measurement of atmospheric neutrino oscillations, mass hierarchy.
- Improved calibration of IceCube
- Technology development for developments beyond the Upgrade.

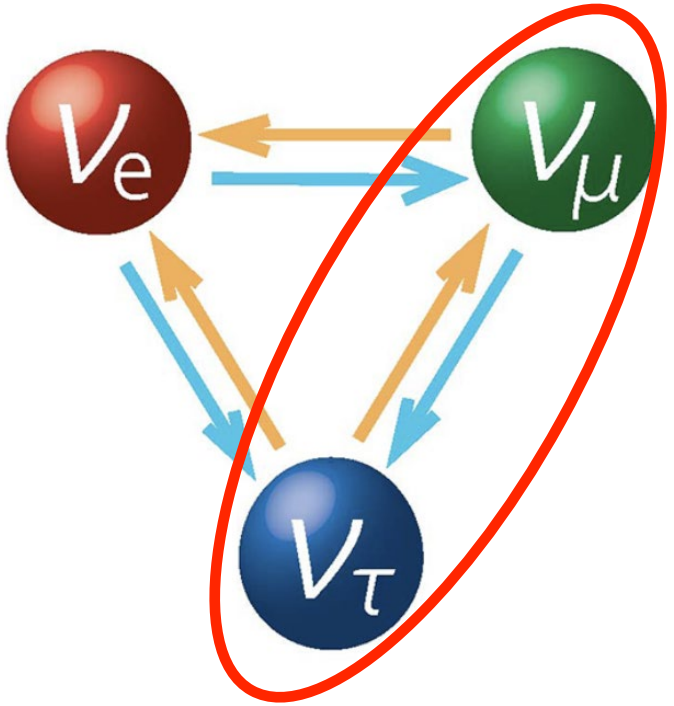
Ongoing construction;

Scheduled completion 2025/26.

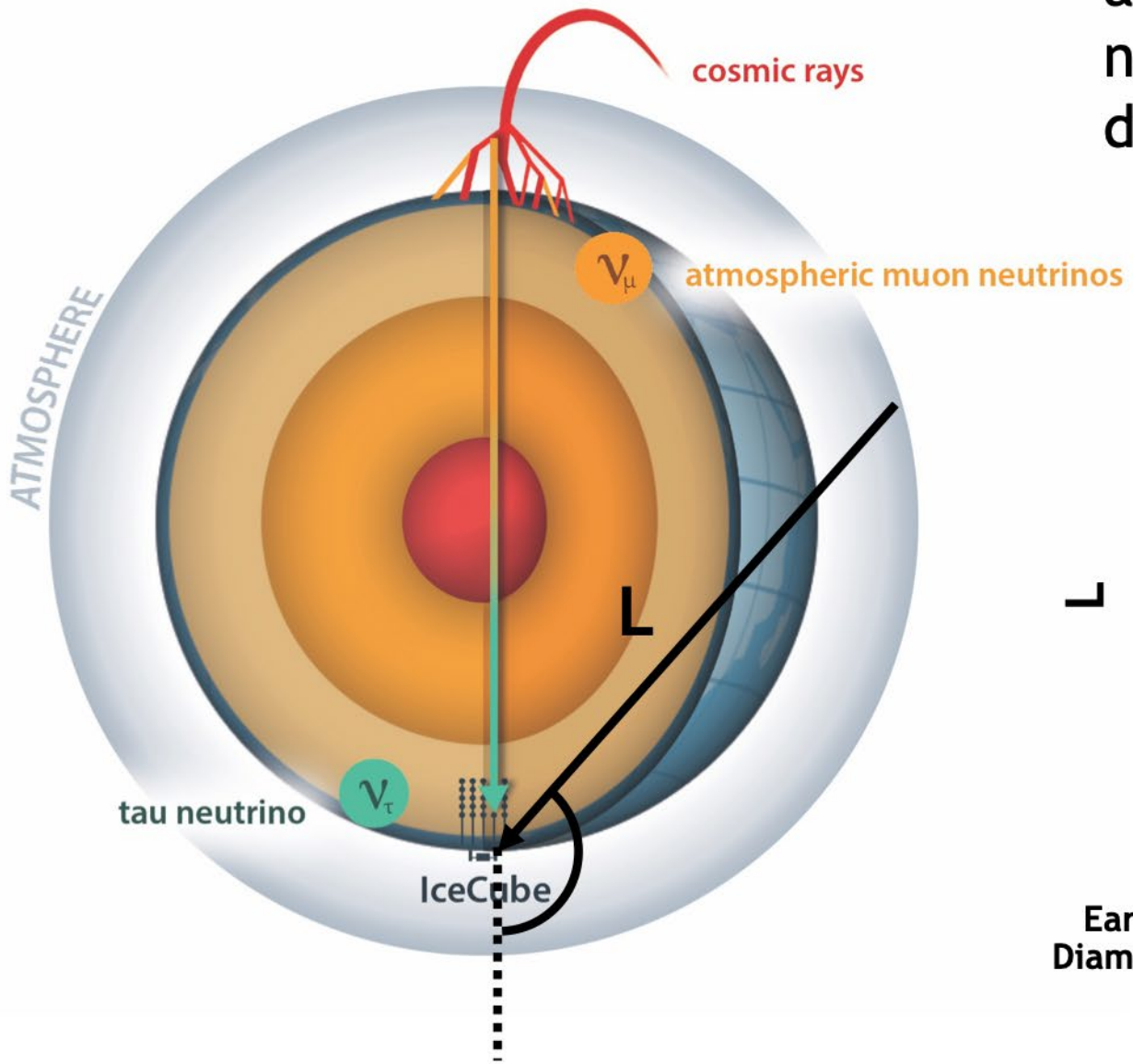
Neutrino physics with atmospheric neutrinos:

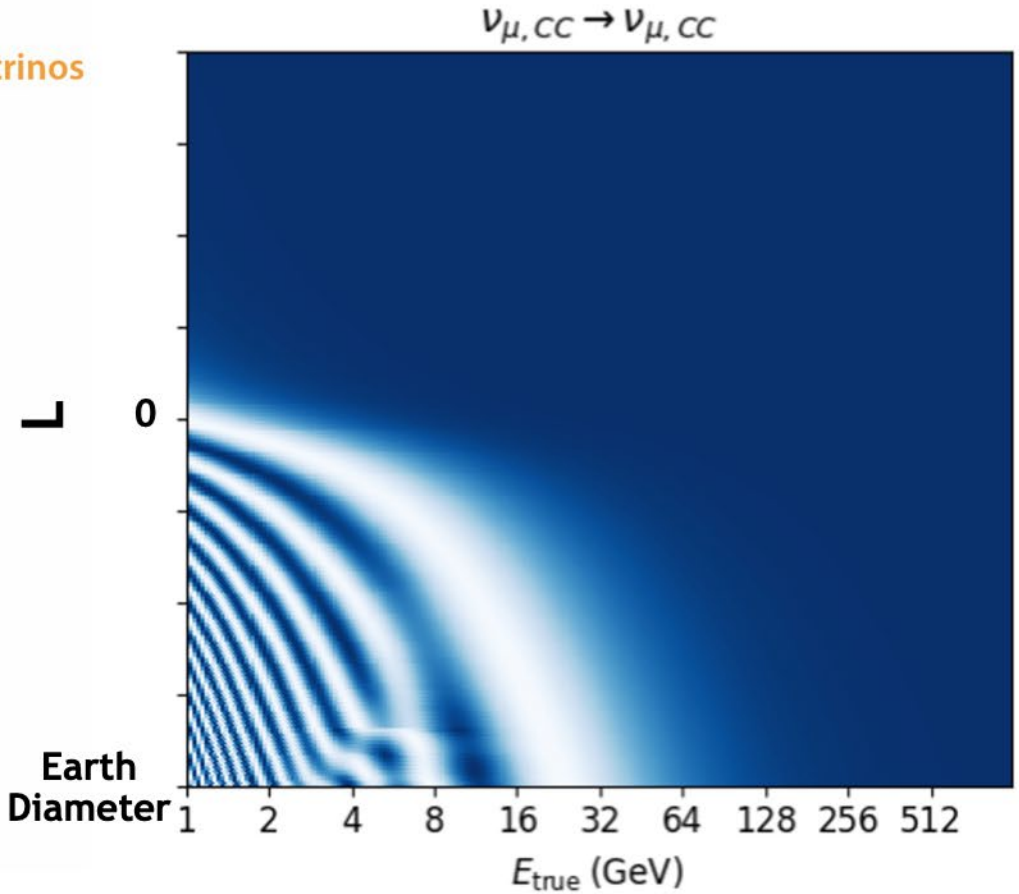
Neutrinos change their identity – their “flavor” – as they travel large distances.





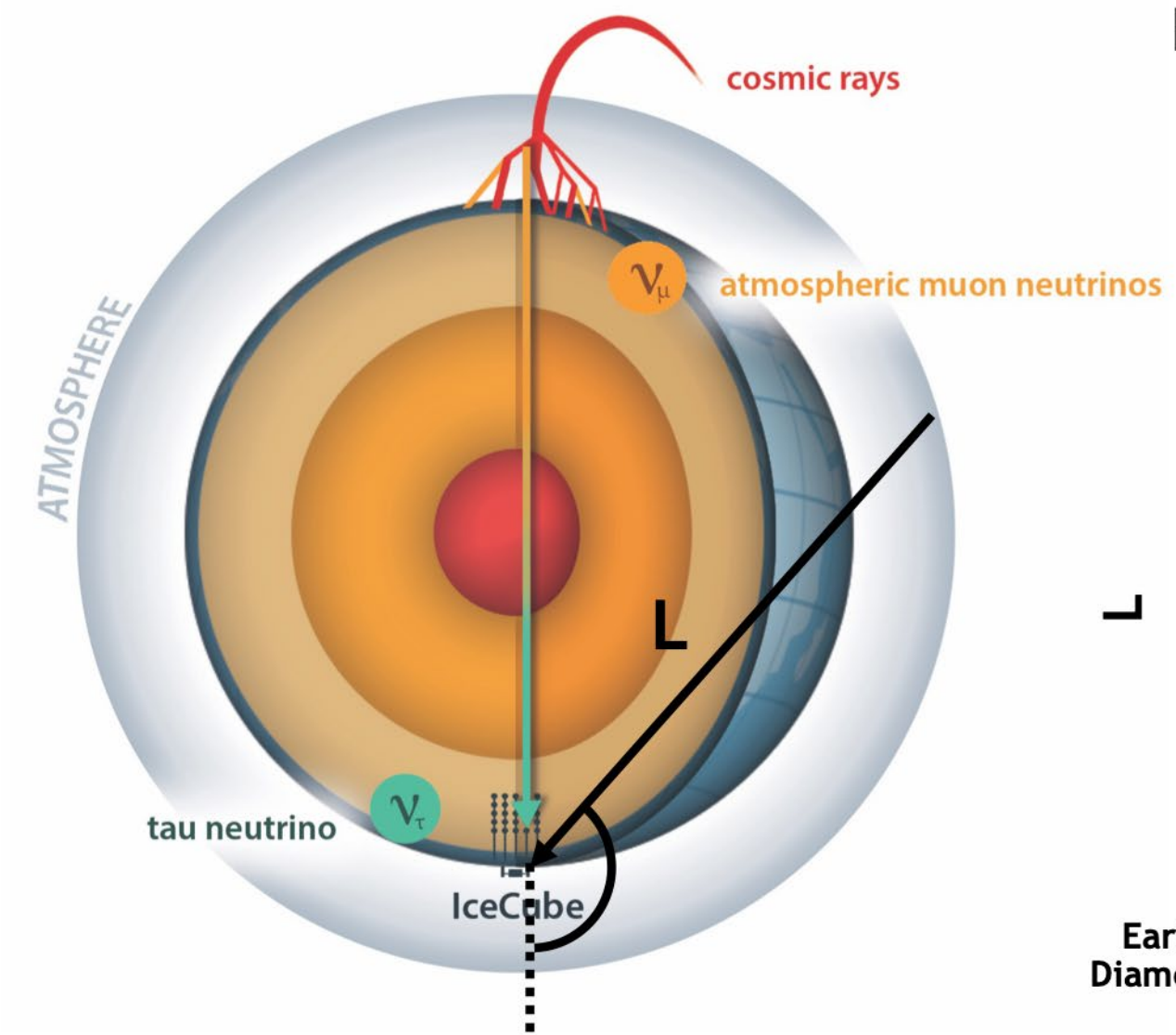
But we don't just have 1 energy and 1 distance, IceCube detects neutrinos of many energies and distances

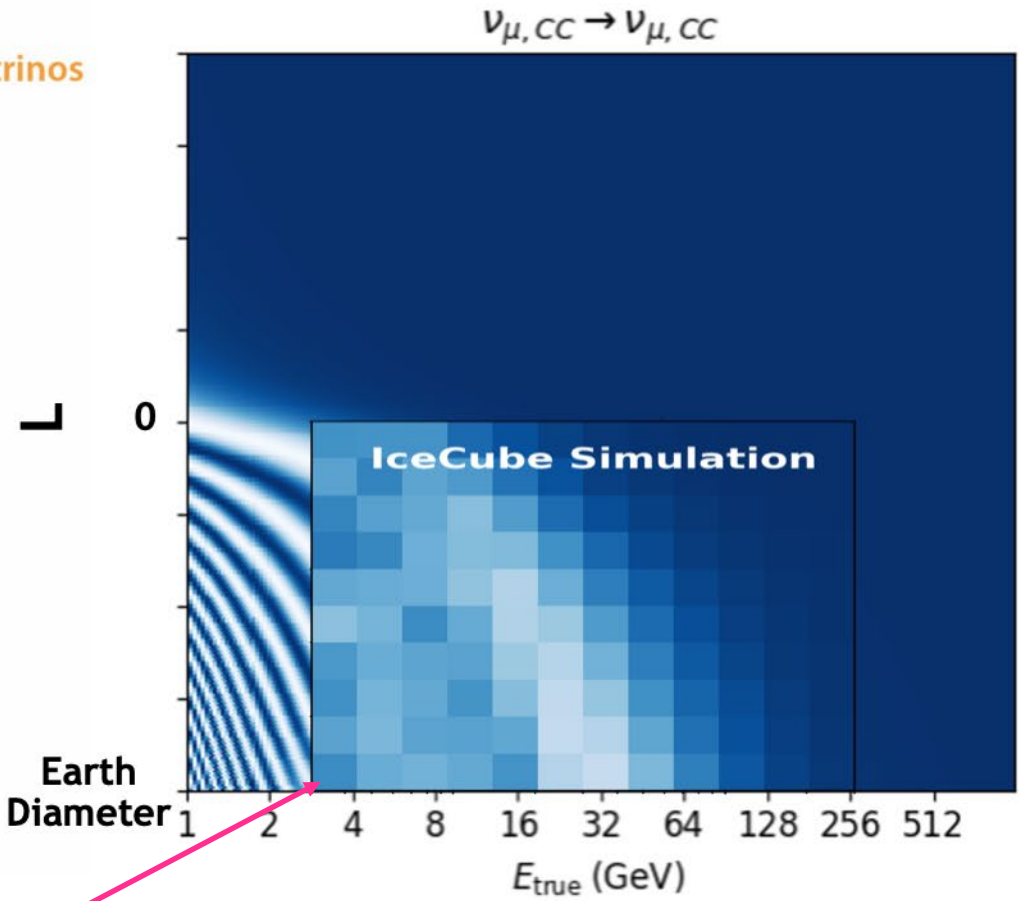




But the reality is more blurry

(Will look better with 200,000 events)



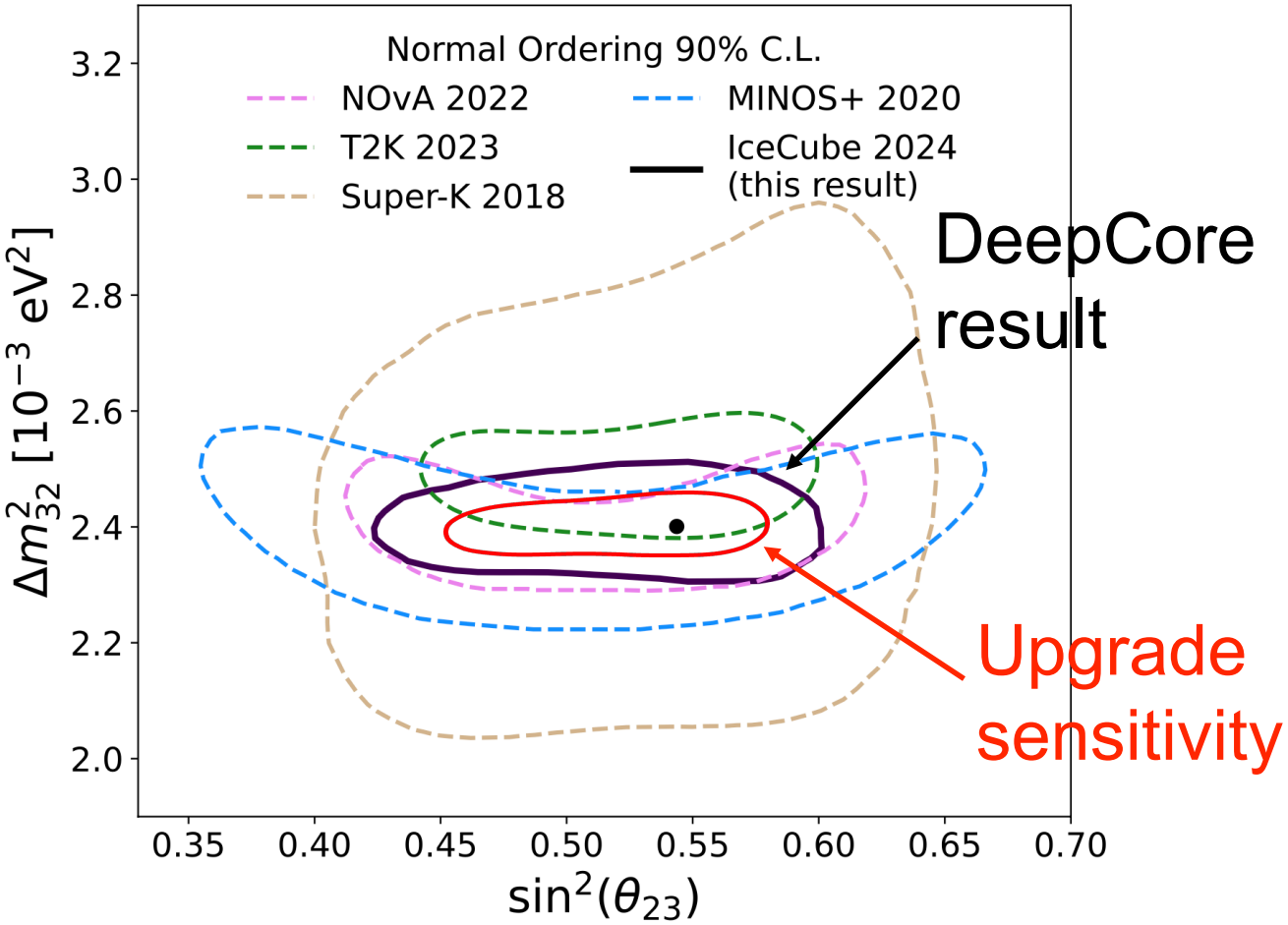


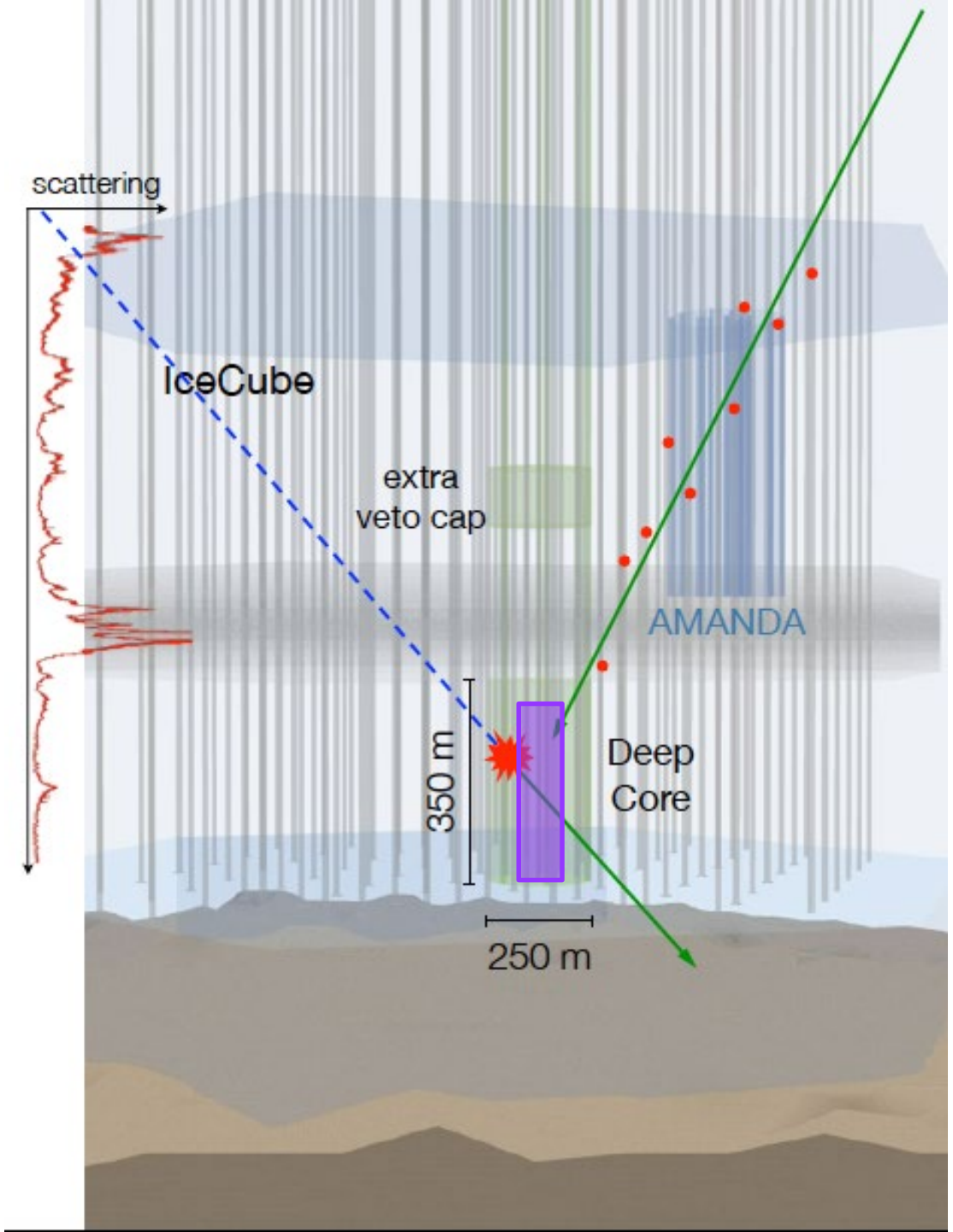
Limited MC statistics

Neutrino physics with IceCube DeepCore+Upgrade

10 years of data = 10 years of lifetime
150,000 neutrino events (cosmic ray muon background < 1%)

https://arxiv.org/abs/2405.02163

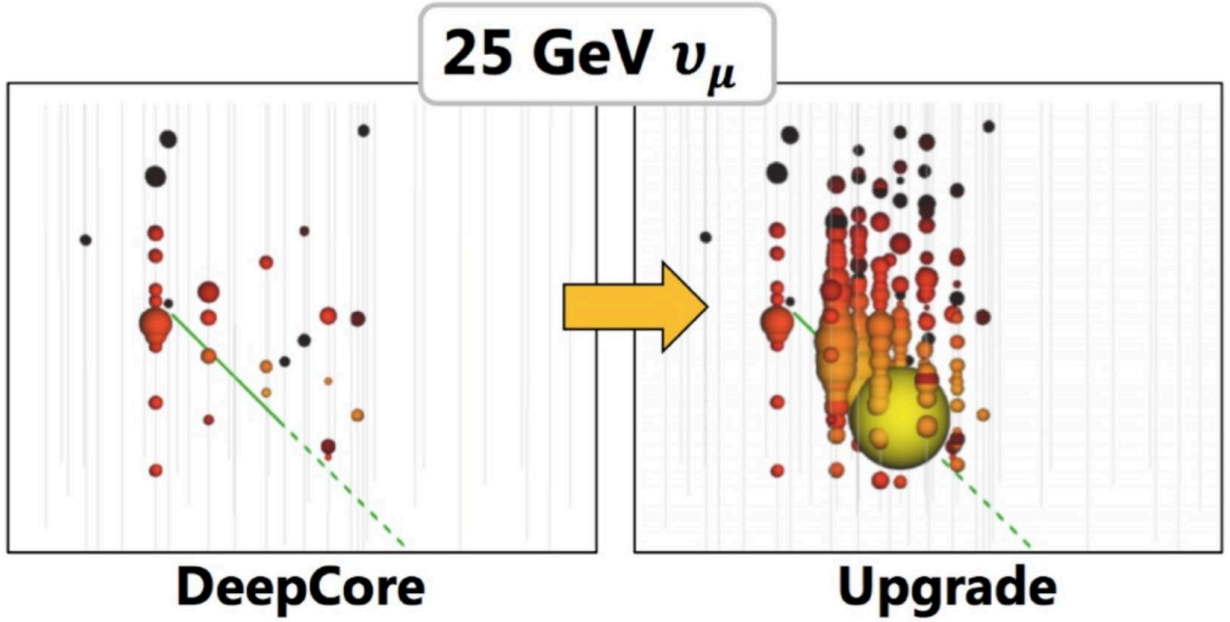


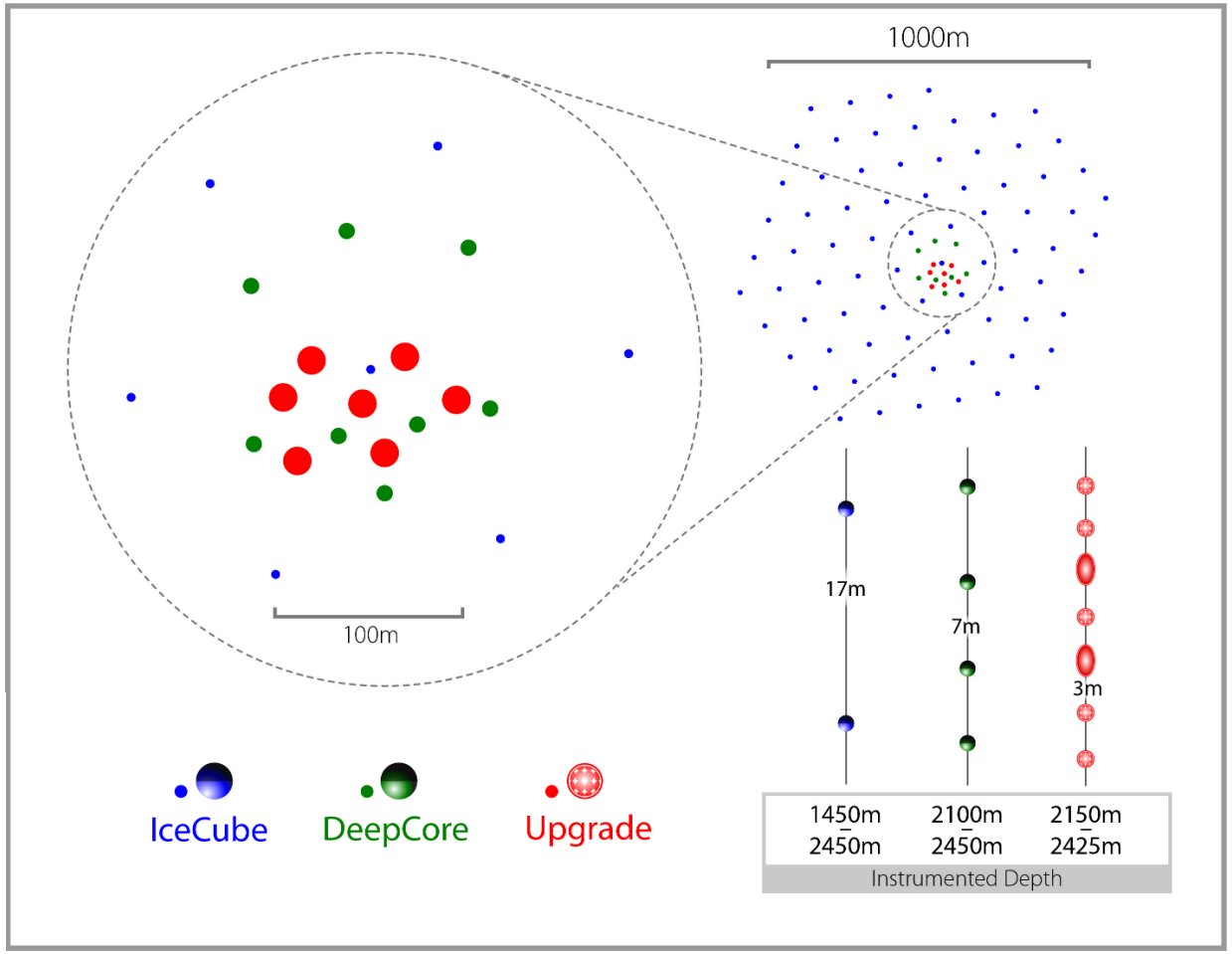


The IceCube-Upgrade

Scope:
Add 7 new strings, 700 sensors, densely packed in the center of IceCube.

Instrumented volume: 2 Mt
Energy threshold: ~ 1 GeV

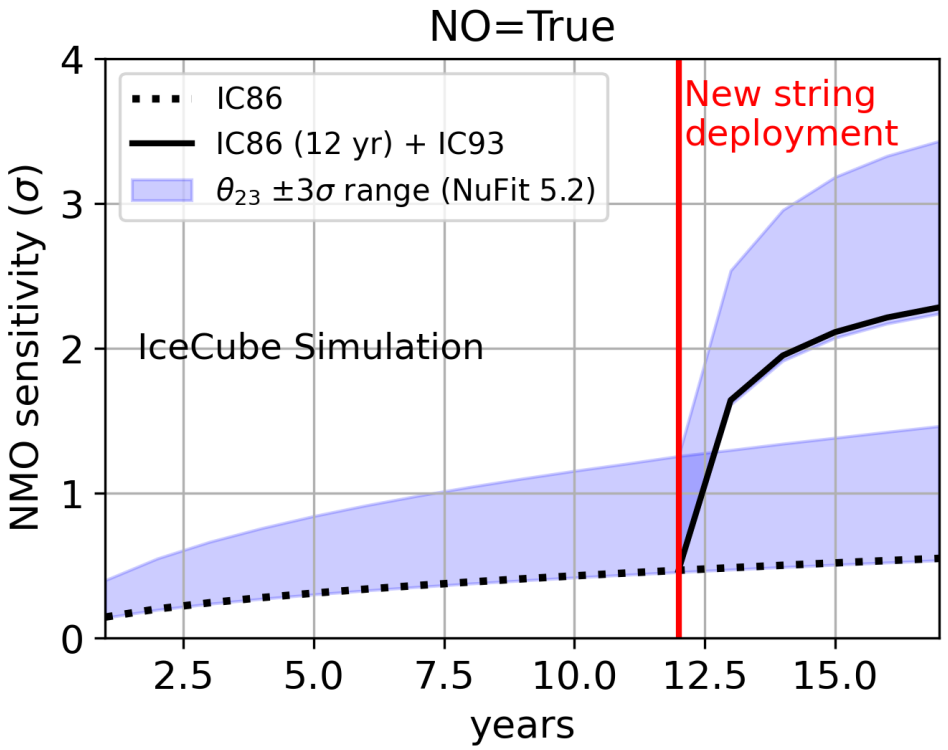




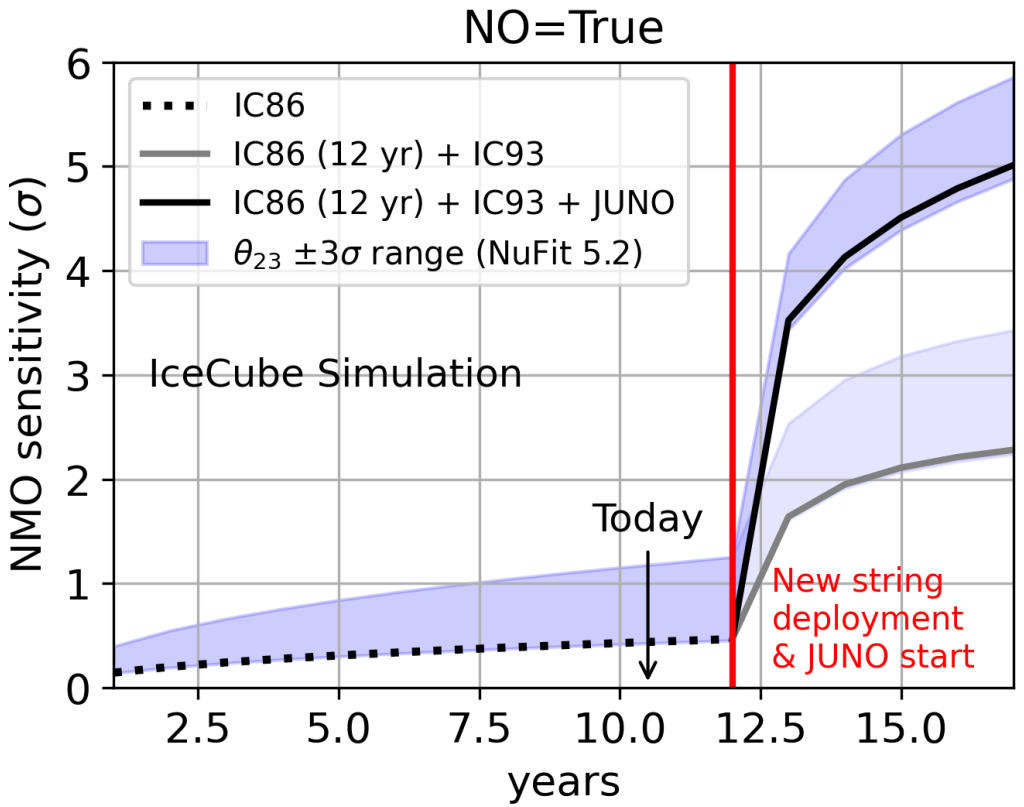
Installation: 2025/26 South Pole season.

A fundamental question:
What is the mass hierarchy of neutrinos?

IceCube + Upgrade: 3 sigma/3 yrs

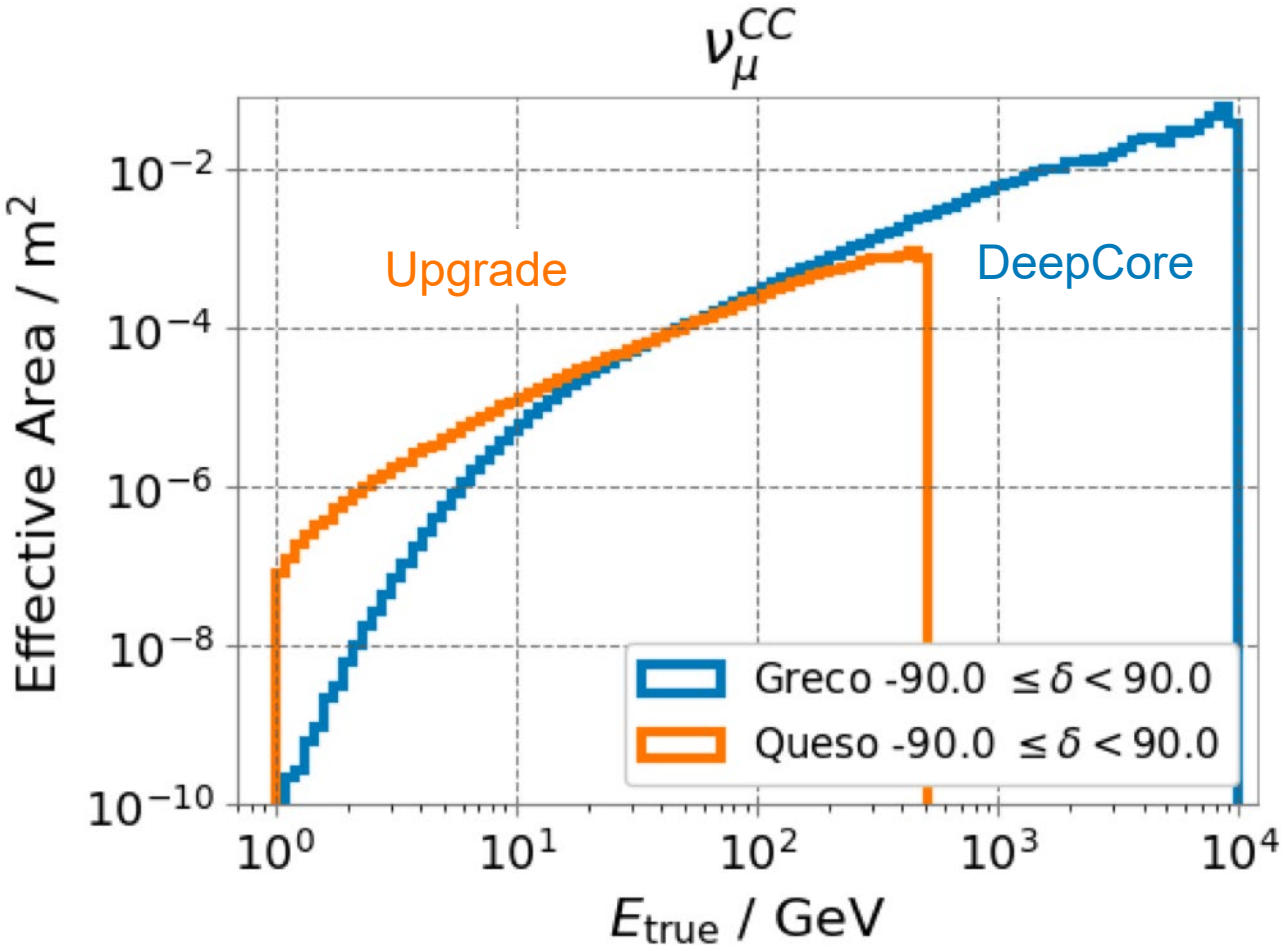


IceCube Upgrade+JUNO: 5 sigma/3 yrs

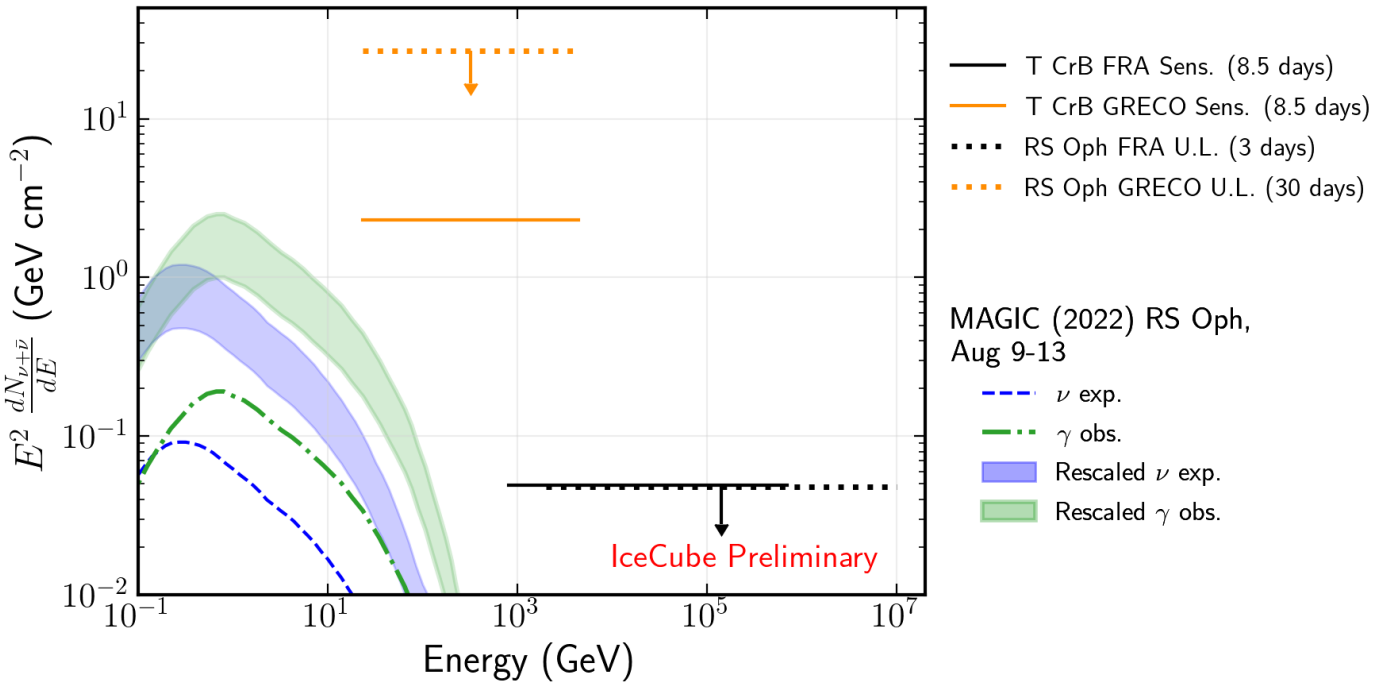


1–1000 GeV neutrino astrophysics

- Six IceCube journal papers on 1–1000 GeV astrophysics with DeepCore
  - All-sky transient searches (two)
  - Gamma-ray bursts
  - Gravitational waves
  - Novae including RS Ophiuchi
  - GRB 221009A (Brightest of All Time)
- Fermi LAT has proven the abundance and diversity of GeV sources, many of which are hadronic
- **Upcoming eruption of nova T Coronae Borealis**



A (somewhat) predictable GeV transient: Upcoming eruption of nova T Coronae Borealis



- Novae: thermonuclear explosions on white dwarfs that somehow act as GeV–TeV particle accelerators
- T Coronae Borealis, expected to outburst between 2024 and 2028, will be ~10x brighter than a bright 2021 nova (RS Ophiuchi) and at a near optimal declination (+26) for IceCube DeepCore/Upgrade
- Likely to be bright in GeV and TeV gamma rays, maybe also neutrinos

Field Season Activities at the South Pole 2024/25

Primary goal:
- Complete drill for the active drilling season in 2025/26 (6 months from now)
- Get the surface instrumentation ready, cables and DAQ hardware.

IceCube operations activities:
- Any kind of urgent maintenance
- Deploy 2 cosmic ray stations (stretch goal)

IceCube Population

The IceCube population reached full strength on December 21.

Total population (ICU + M&O): 30

- **Upgrade total: 20**
  Project office (PI/PD/Safety): 2,
  Upgrade drilling: 14,
  Upgrade installation: 4

- **IceCube M&O (includes Upgrade support and winterovers): 10**

The IceCube Field Team on December 31. The team is enjoying a 2-day break.

Some measures taken to minimize impact of personnel shortage in EE area:

- Enlisted Anatili Feydinitch, Academica Sinica, Taiwan (Physics Prof. and EE)
- Recruited Jennifer Wang, an electrical engineer with controls SW experience.
- Reassigned Physics RA (Vedant Basu) with technical and SW skills to drill electronics and HW, extended his stay.

Installation

- All 7 surface cables have been pulled up the tower and through the bridge to the ICL.
- All cables are tested and connected to “Fieldhubs”, the electronics in the ICL.
- Fieldhubs are also tested

Chris Ng, MSU, inspects the cable tray in the ICL.

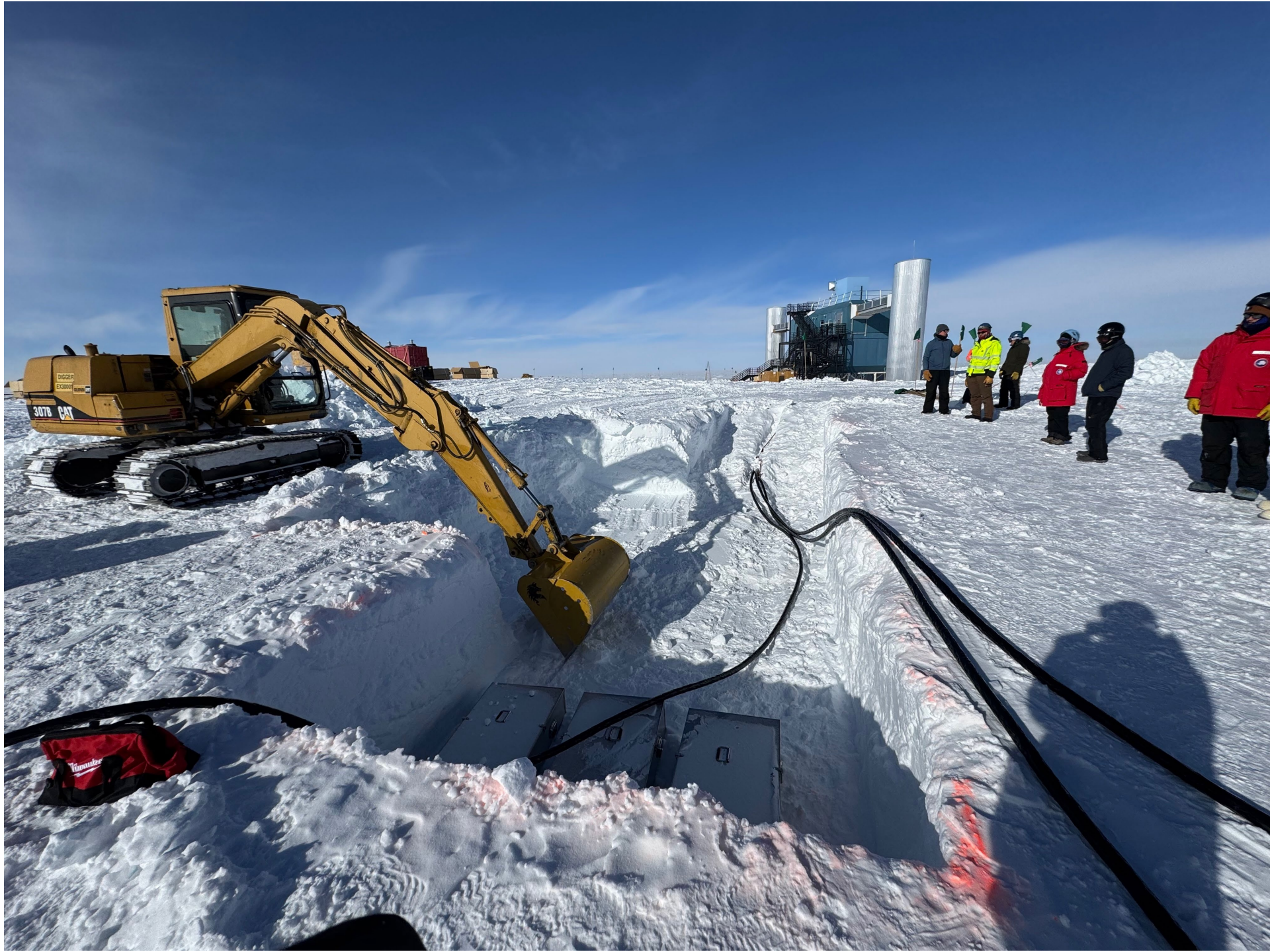
Karl-Heinz Sulanke, DESY, explains the field hub electronics.

IceCube Upgrade field work

South Pole
January 16, 2025

Photo: Michael Rayne/ASC-ARFF

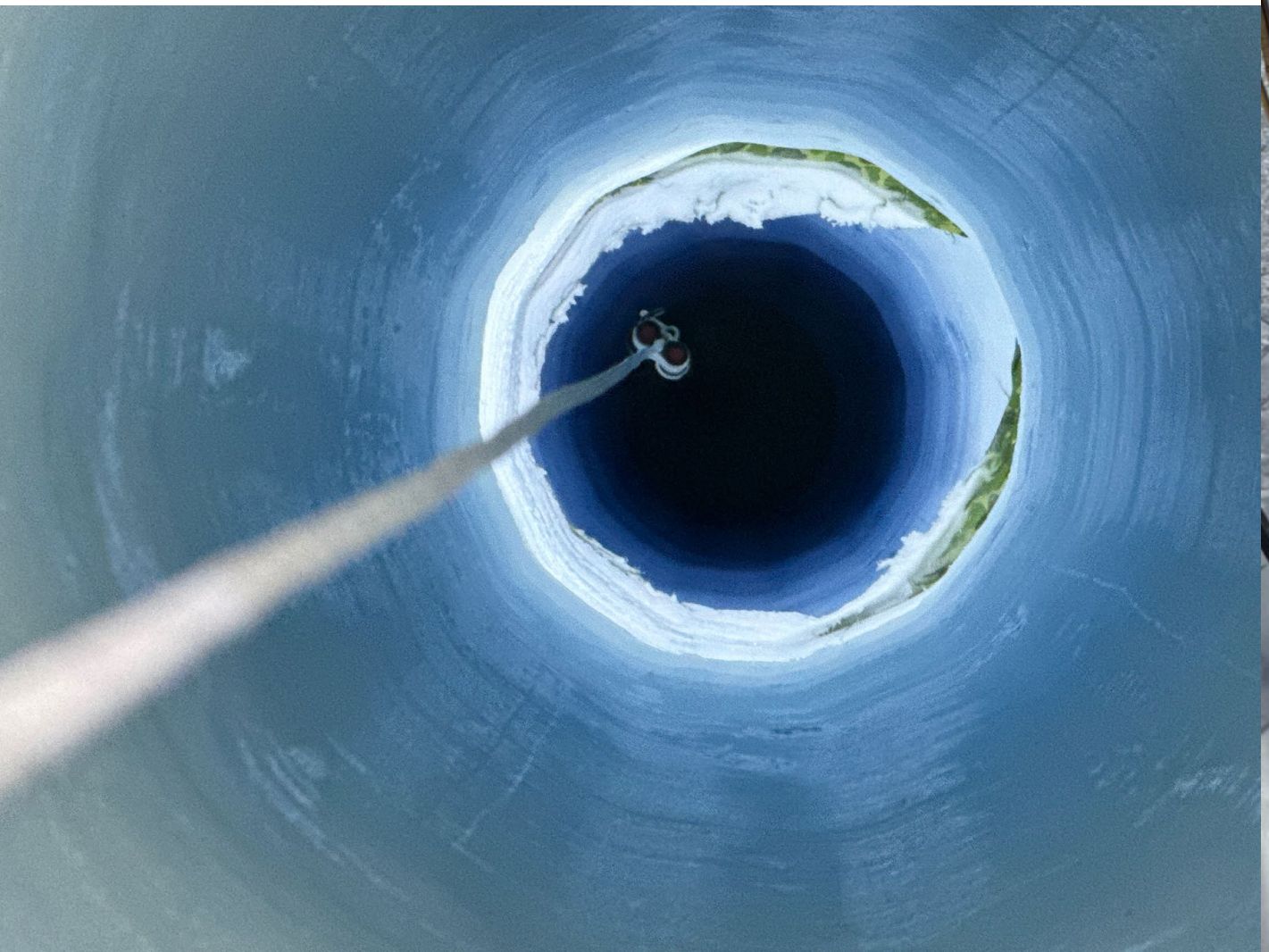
Preparation for 2025/26 installation

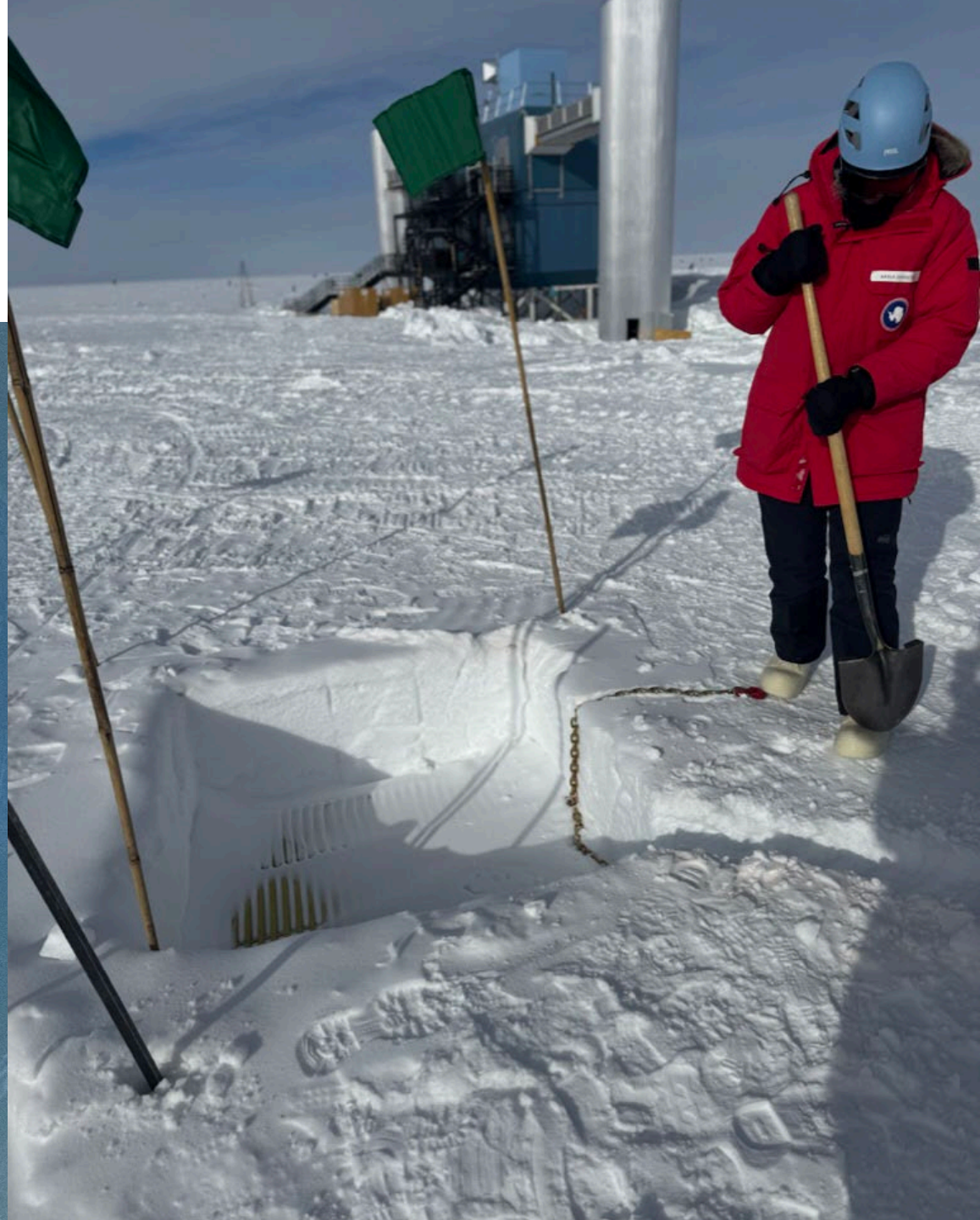


January 2025

Equipment operator at the excavation of the surface junction box pits.

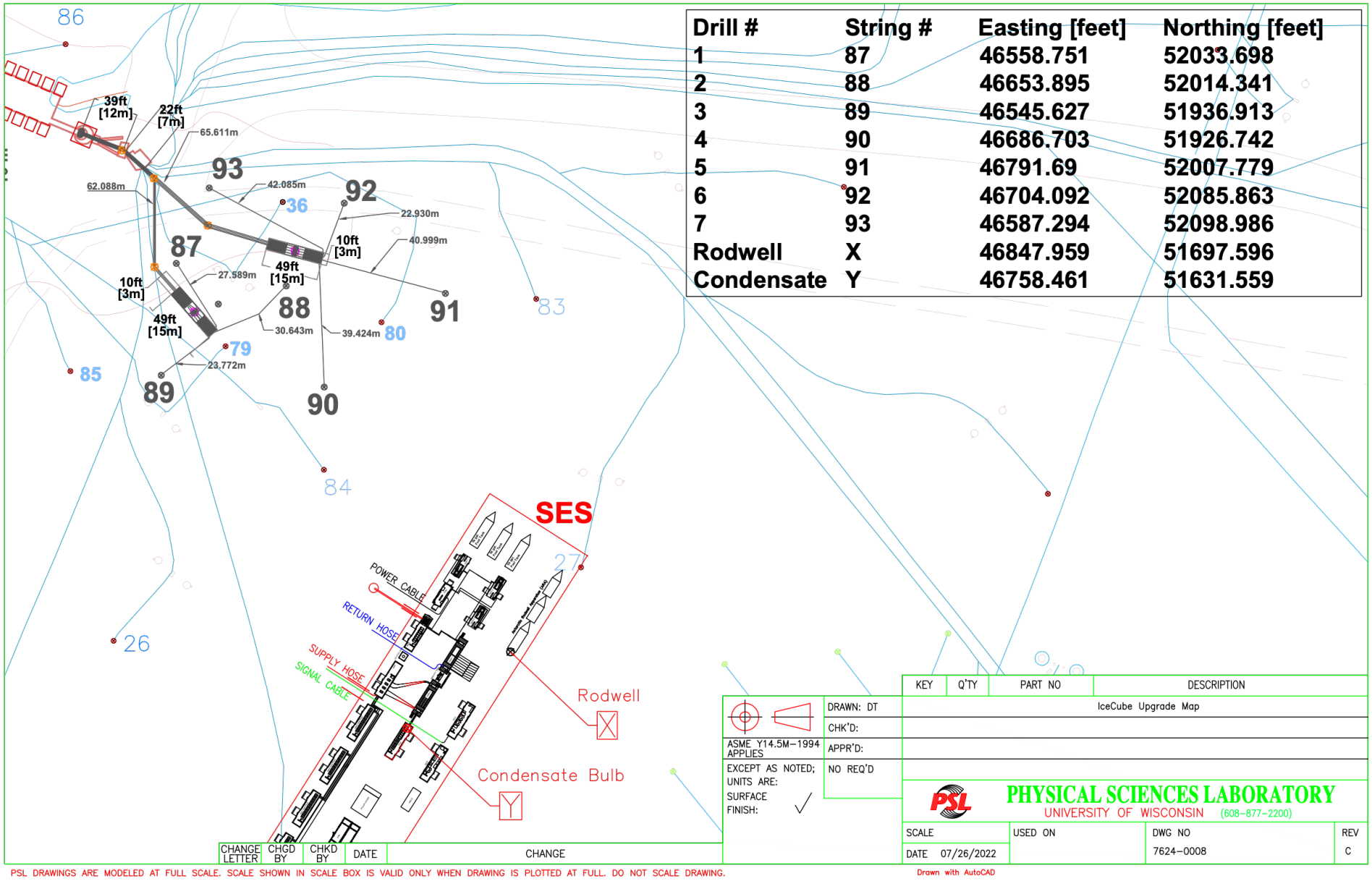
All firn holes drilled,
anchors are prepared.





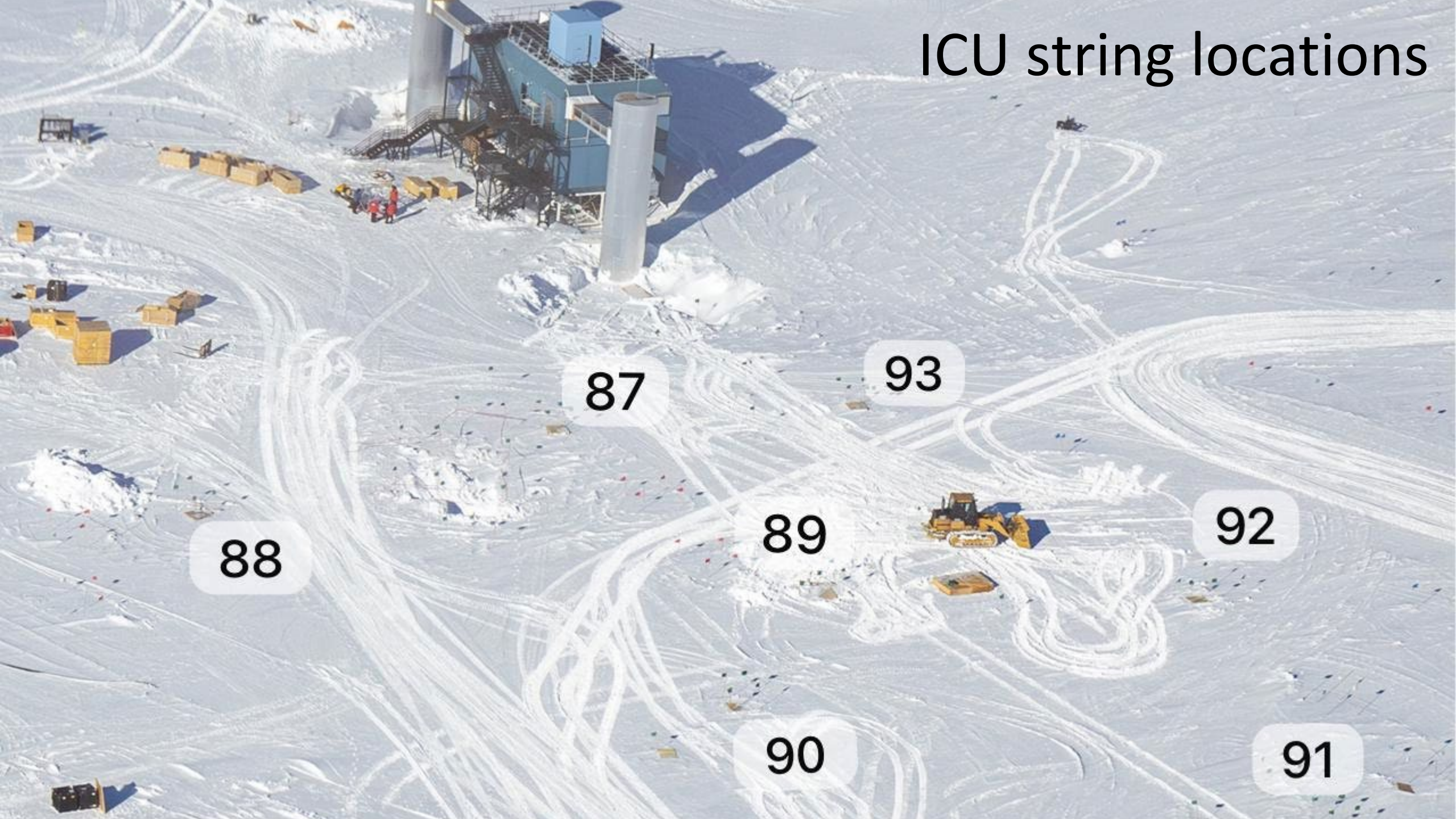
All seven holes are prepared

- **Firn holes drilled**
- **String anchors in place**

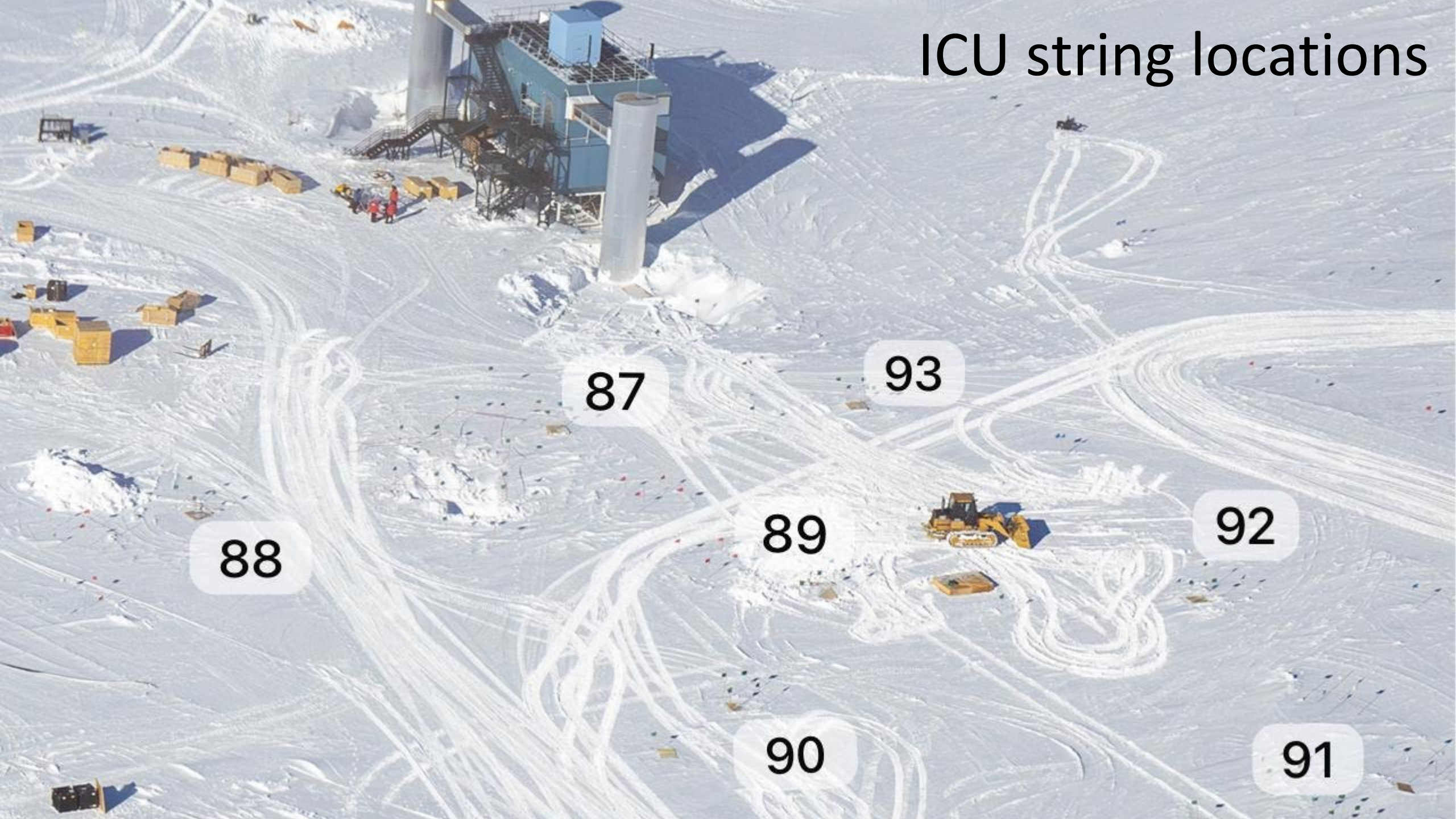


Drill #	String #	Easting [feet]	Northing [feet]
1	87	46558.751	52033.698
2	88	46653.895	52014.341
3	89	46545.627	51936.913
4	90	46686.703	51926.742
5	91	46791.69	52007.779
6	92	46704.092	52085.863
7	93	46587.294	52098.986
Rodwell	X	46847.959	51697.596
Condensate	Y	46758.461	51631.559

ICU string locations



ICU string locations



Seasonal Equipment Site

- Water circulation successful through all major modules under pressure.

Snow ramp to one of two large hotwater tanks.

Terry Benson (from left) tours the drill camp with Dr. Jean Cottam Allen, acting director of NSF's Office of Polar Program, Sheryl Seagraves (ASC, Science Implementation Manager, Dr. Linnea Avallone, Chief Officer of Research Facilities, Office of the Director, and Albrecht Karle. (Photo: A. Karle, IceCube/NSF)

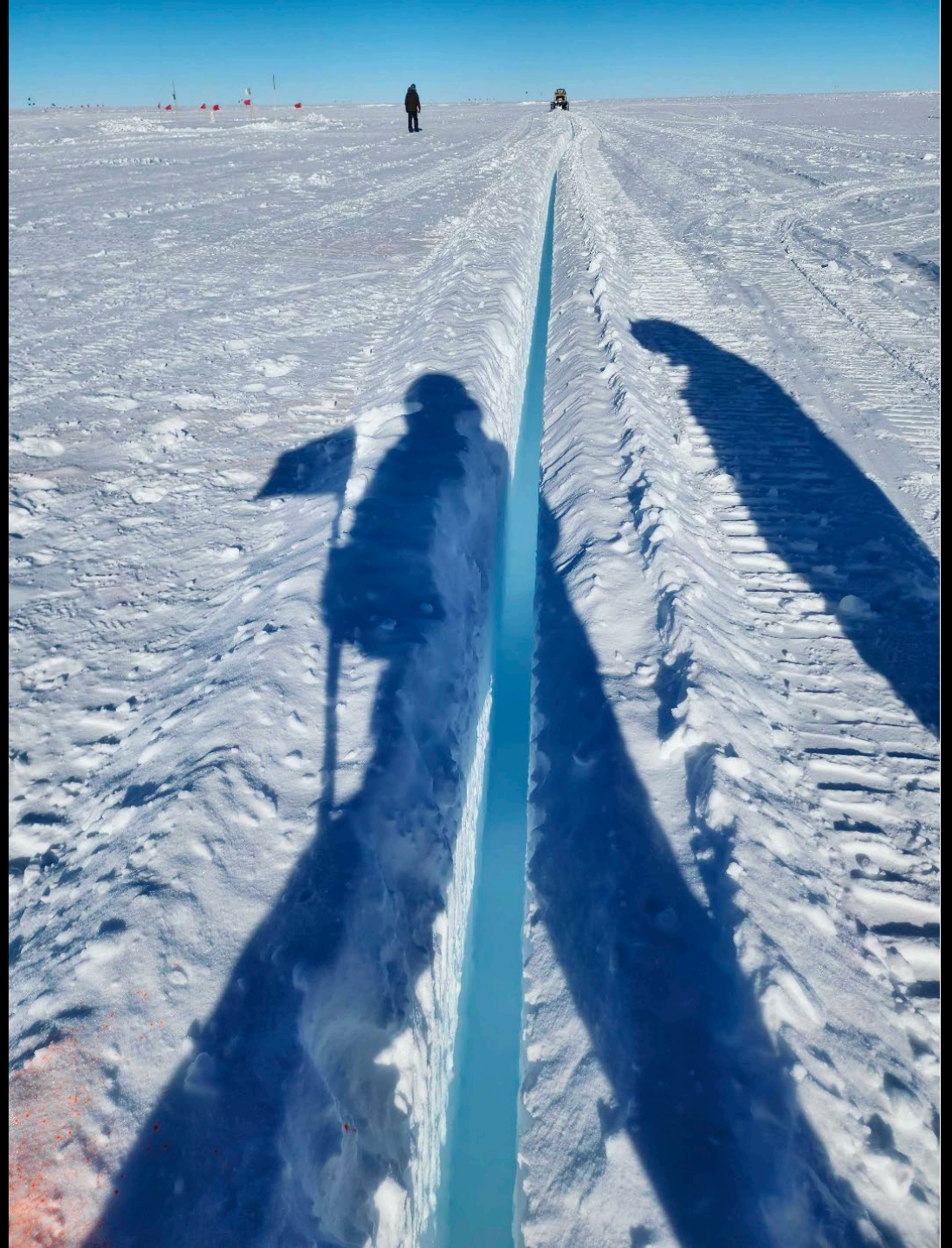
Looking forward:

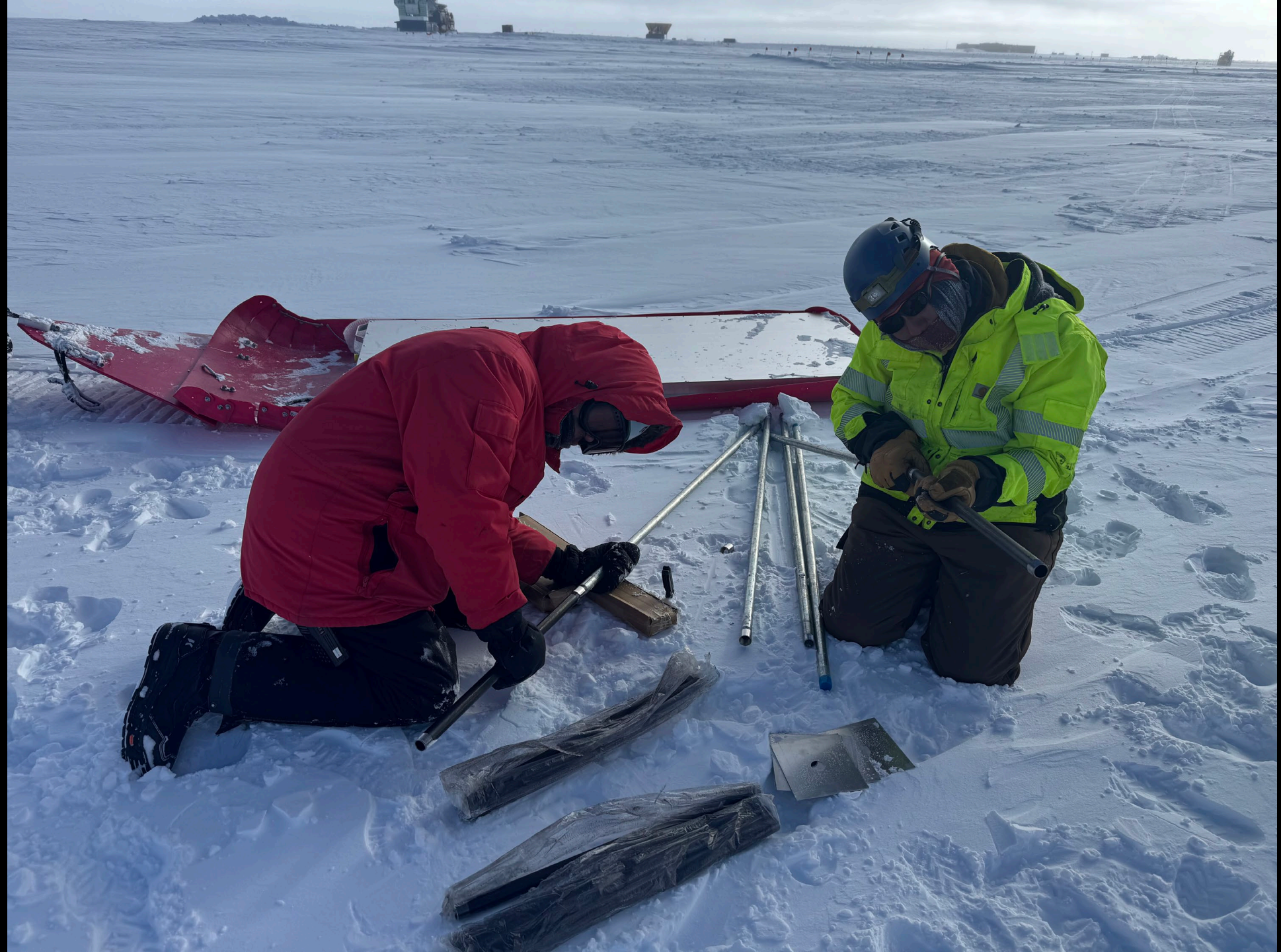
We will have a challenging season, starting in just 6 months.
We will not be immediately ready for drilling - and it is the first deep drilling since 2010/11.

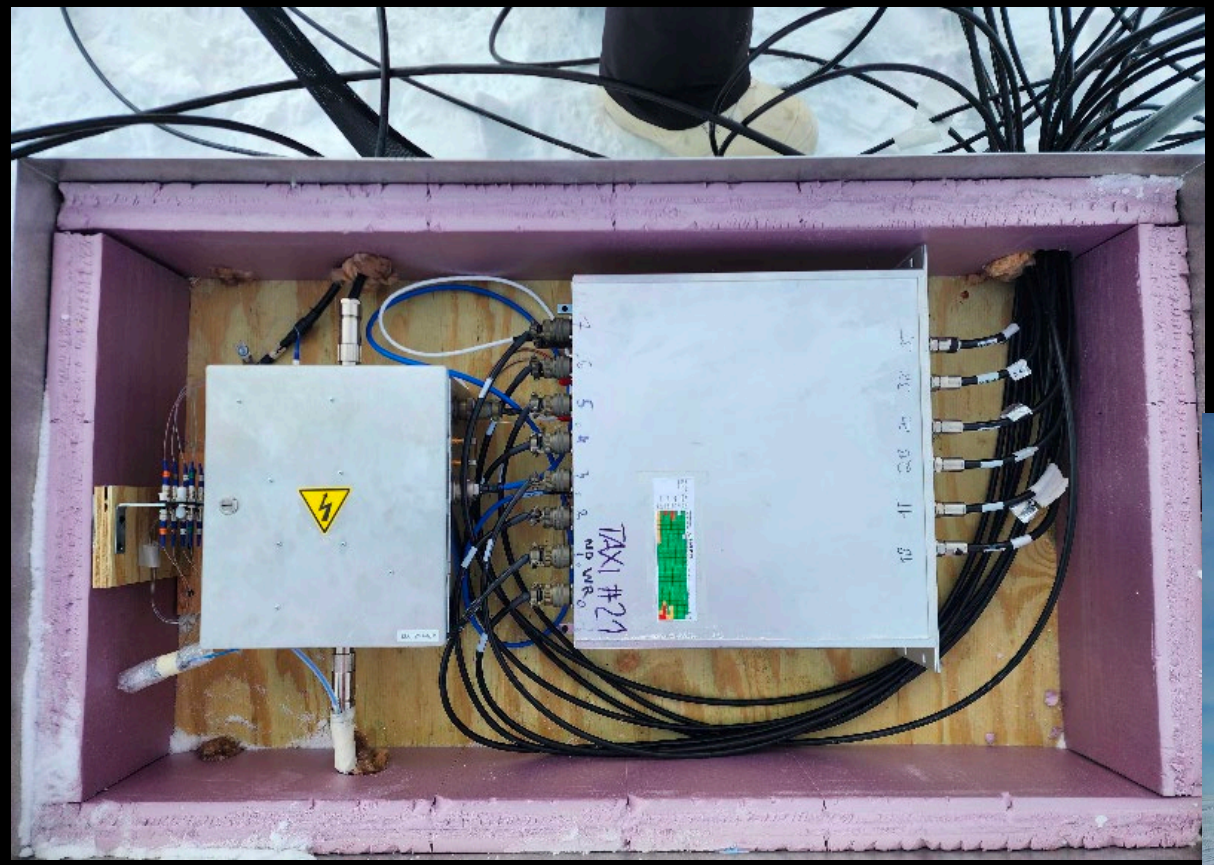
We are in OK shape. Some control software is still being written.
We will use only one tower for drilling and installation (not two) - that’s OK.
Will try to get started on December 15.

Our goal is to deploy 7 strings.

Deployed two Cosmic ray detector stations






TAXI #21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Backup

IceCube Operations and Maintenance 2026-2031

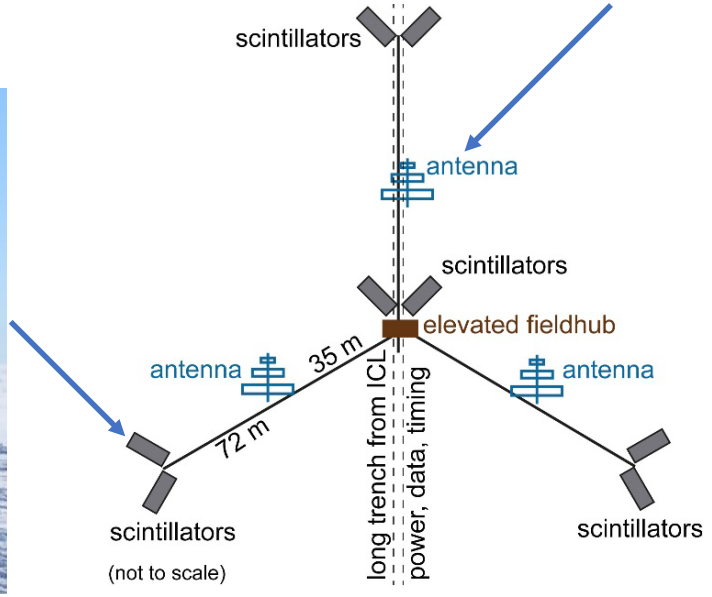
Proposal is submitted.

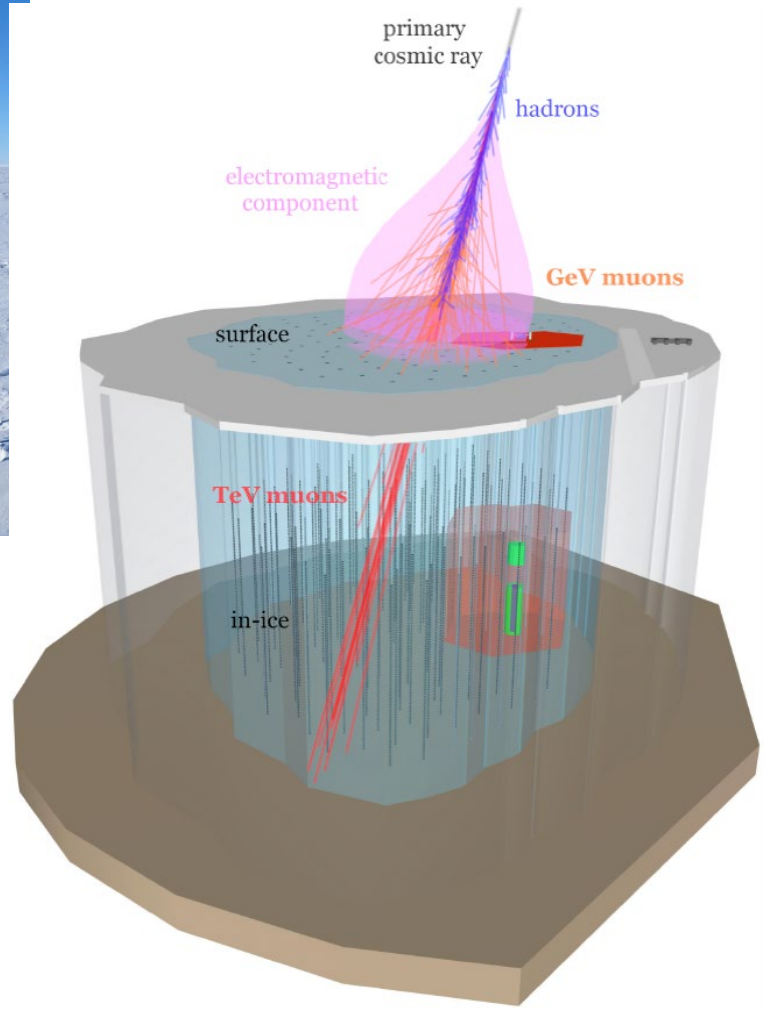
The Karlsruhe Institute of Technology (KIT; Karlsruhe, Germany) is providing instrumentation for the IceTop surface array enhancement stations in this proposal.
This includes up to 144 scintillator panels and up to 54 log-periodic dipole antennas, sufficient for 18 detector stations.
KIT will also provide existing data acquisition electronics for 4 stations.
Funding permitting, KIT will provide the engineering effort to develop upgraded DAQ electronics and produce these electronics for up to 18 detector stations.

KIT also provides significant computing resources for IceCube cosmic-ray simulation production.

IceCube-Gen2: The Surface Array

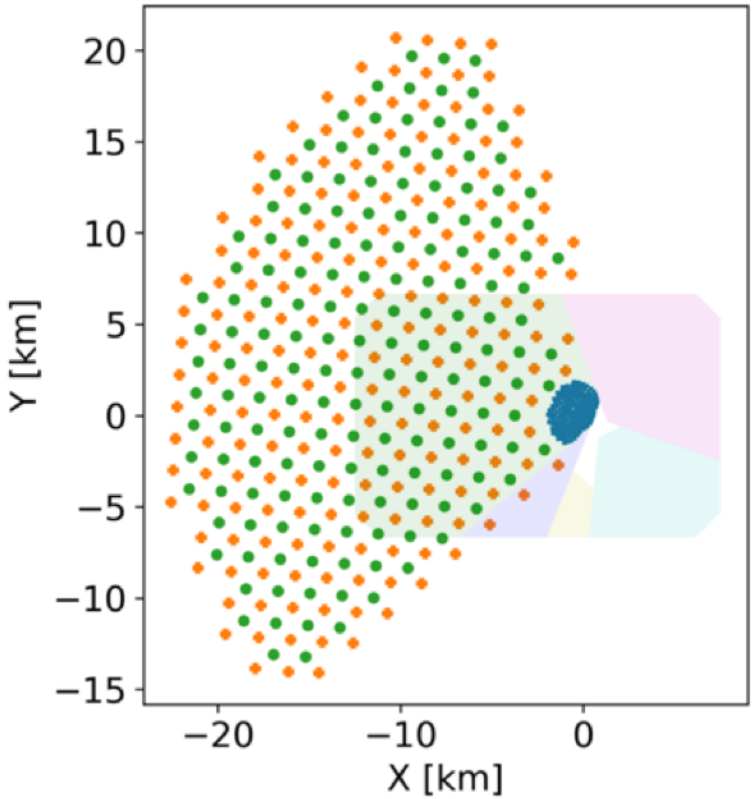
- Veto for larger and purer sample of PeV neutrino candidates
- High accuracy for cosmic rays in the PeV to EeV region
  - particle physics in air showers
  - cosmic-ray astrophysics





Scope: 3. The Gen2 radio array

Energy range from 30 PeV to well beyond EeV



361 stations

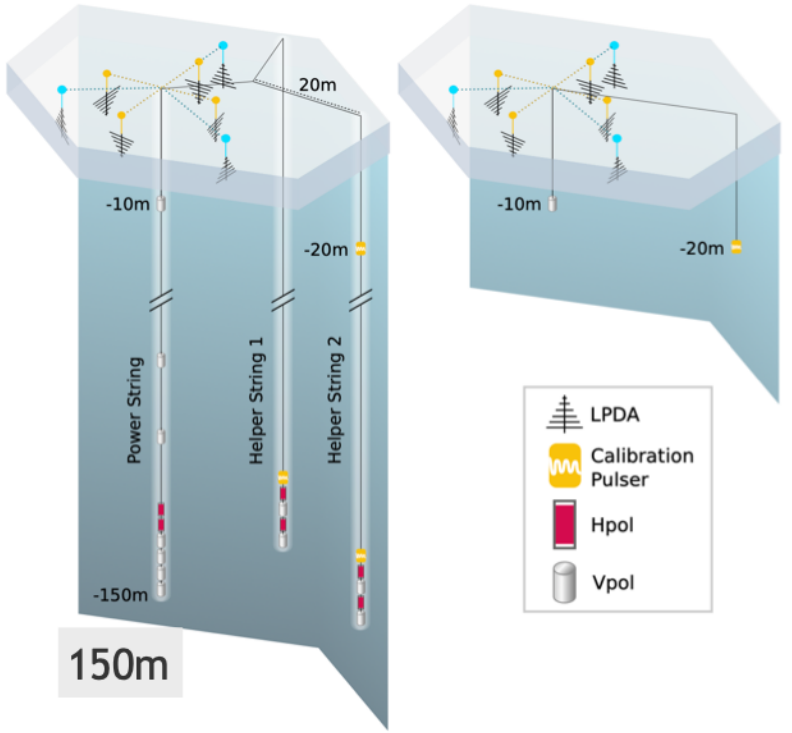
Area: 500 km²

Ice target: 1000 km³

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

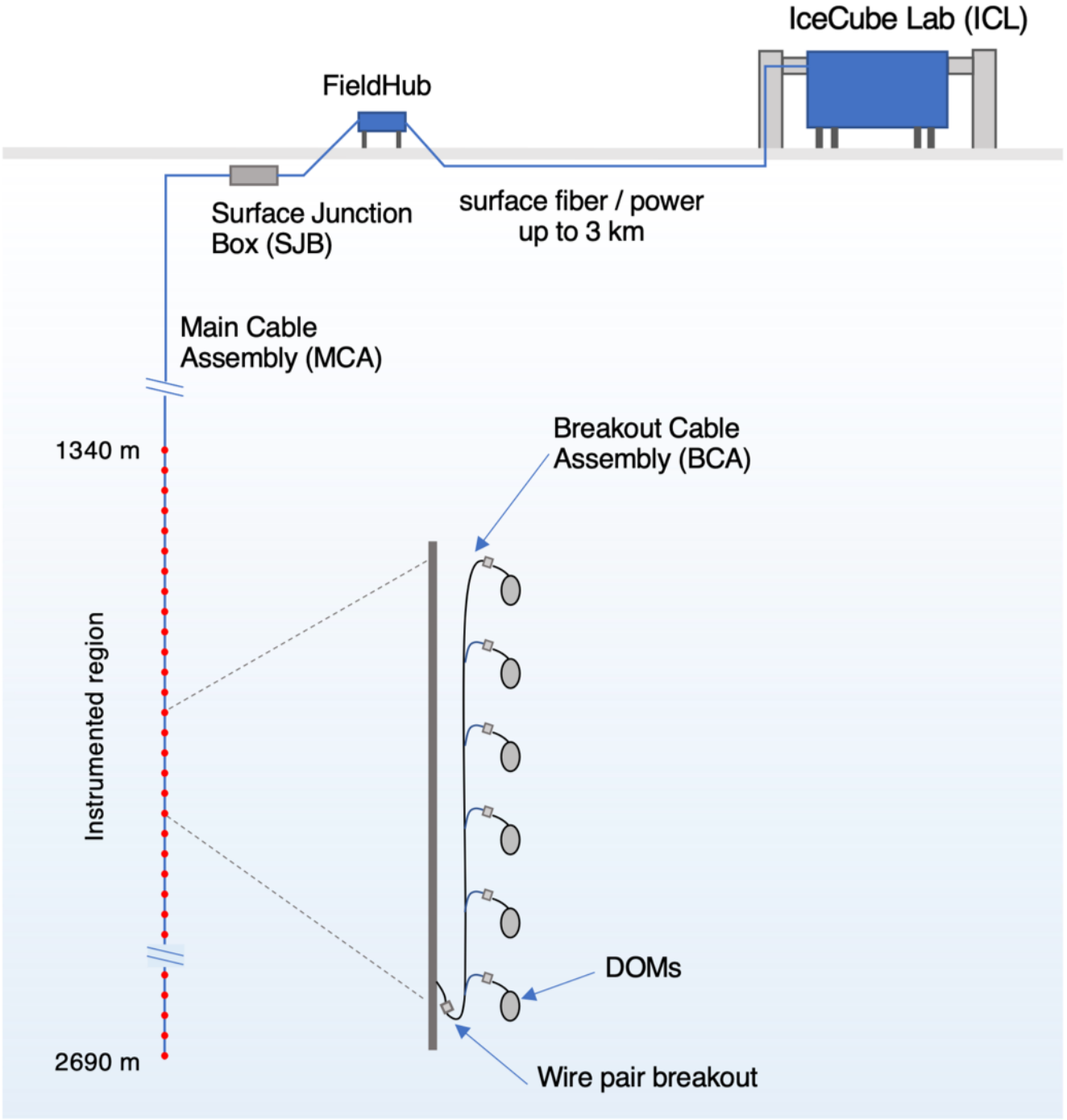
RNO-G:

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



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

Higher Sensor sensitivity —> Larger Muon Effective Area

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