

IceCube Upgrade
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Chiba University
Sep 10, 2026



From the early days to the IceCube Upgrade

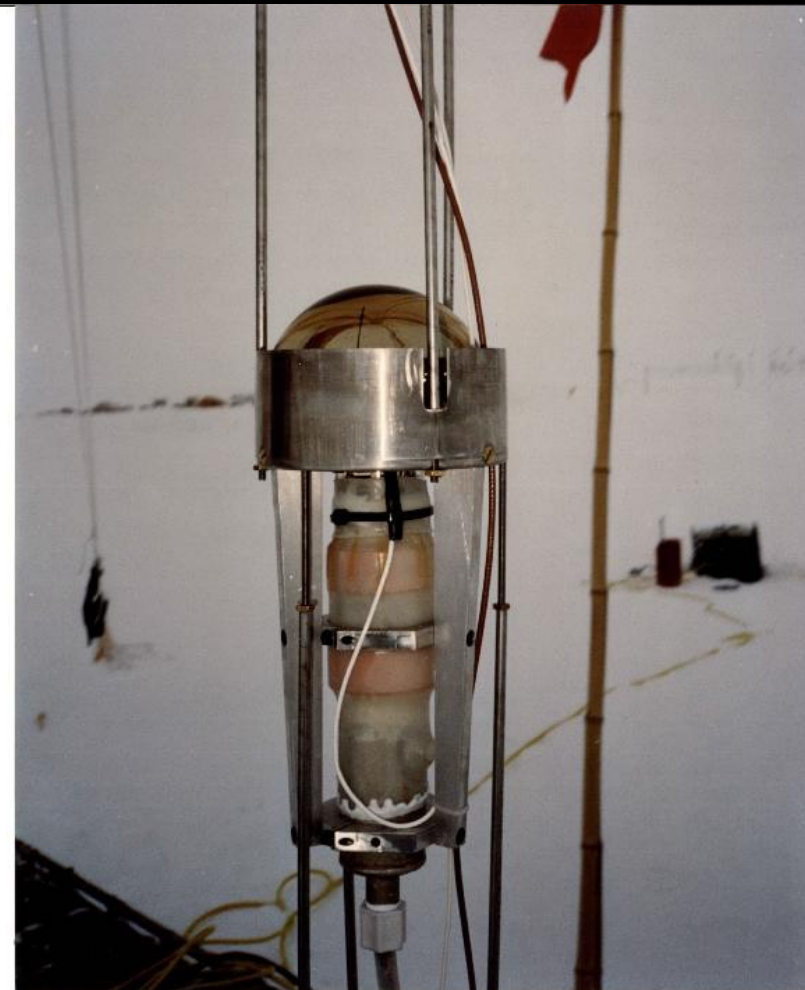
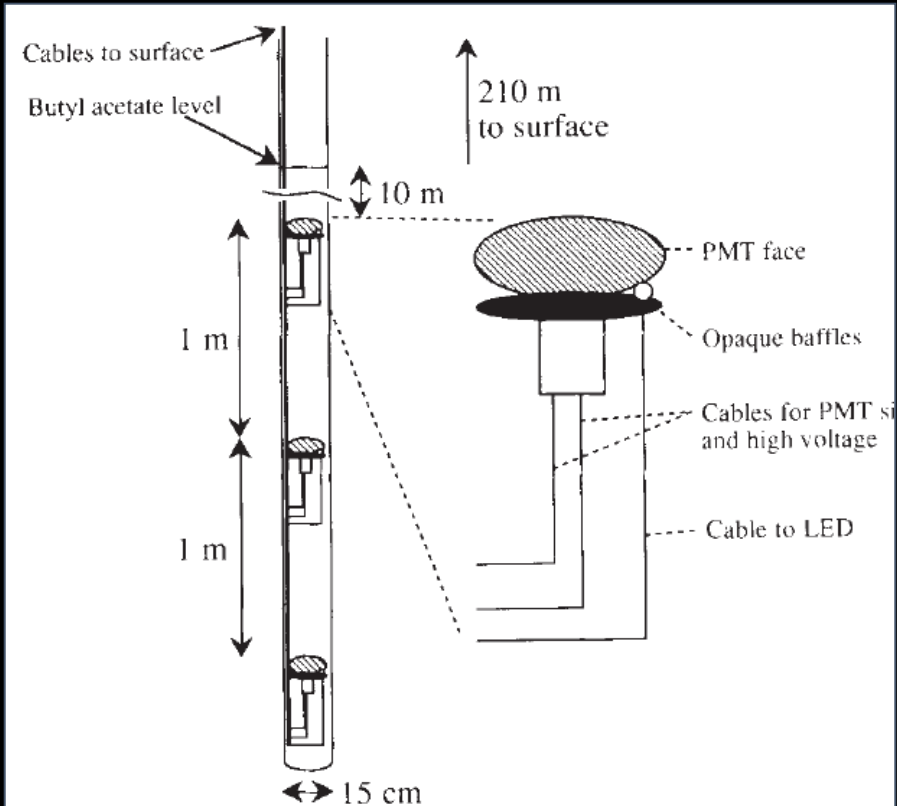
1990: Detection of cosmic ray muons using PMT in natural ice in Greenland.

Nature 353, 331-333 (26 September 1991)

Observation of muons using the polar ice cap as a Cerenkov detector

D. M. Lowder*, T. Miller*, P. B. Price*, A. Westphal*, S. W. Barwick†, F. Halzen‡ & R. Morse‡

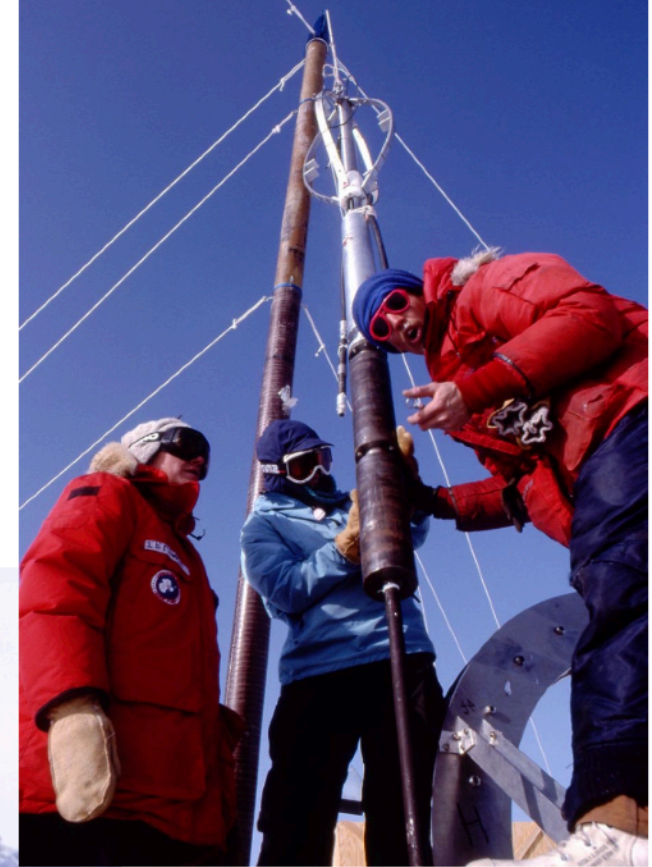
“Cerenkov radiation from muons was detected, and a comparison of count rate with the expected muon flux indicates that the ice is very transparent, with an absorption length greater than 18 m. **Our results suggest that a full-scale Antarctic ice detector is technically quite feasible.**”



1991/92: First tests at the South Pole

- Small PMTs deployed
- First test of hot water drilling at South Pole

Heaters and pumps
to melt the holes



1996/97: add 6 strings to complete AMANDA-B10



1999/2000: AMANDA-II drill site



Observation of high-energy neutrinos using Čerenkov detectors embedded deep in Antarctic ice

E. Andrés*, P. Askebjerg†, X. Bai‡, G. Barouch*, S. W. Barwick§, R. C. Bay||, K.-H. Becker¶, L. Bergström†, D. Bertrand#, D. Bierenbaum§, A. Biron*, J. Booth§, O. Botner**, A. Bouchta*, M. M. Boyce*, S. Carius††, A. Chen*, D. Chirkin||, J. Conrad**, J. Cooley*, C. G. S. Costa#, D. F. Cowen††, J. Dailing§, E. Dalberg†, T. DeYoung*, P. Desiati*, J.-P. Dewulf#, P. Doksus*, J. Edsjö†, P. Ekström†, B. Erlandsson†, T. Feser§§, M. Gaug*, A. Goldschmidt||, A. Goobar†, L. Gray*, H. Haase*, A. Hallgren**, F. Halzen*, K. Hanson††, R. Hardtke*, Y. D. He||, M. Hellwig§§, H. Heukenkamp*, G. C. Hill*, P. O. Hulth†, S. Hundertmark§, J. Jacobsen||, V. Kandhadai*, A. Karle*, J. Kim§, B. Koci*, L. Köpke§§, M. Kowalski*, H. Leich*, M. Leuthold*, P. Lindahl††, I. Liubarsky*, P. Loaiza**, D. M. Lowder||, J. Ludvig||, J. Madsen*, P. Marciniowski**, H. S. Matis||, A. Mihalyi††, T. Mikolajski*, T. C. Miller†, Y. Minaeva†, P. Miočnović||, P. C. Mock§, R. Morse*, T. Neunhöffer§§, F. M. Newcomer††, P. Niessen*, D. R. Nygren||, H. Ögelman*, C. Pérez de los Heros**, R. Porrata§, P. B. Price||, K. Rawlins*, C. Reed§, W. Rhode¶, A. Richards||, S. Richter*, J. Rodríguez Martino†, P. Romenesko*, D. Ross§, H. Rubinstein†, H.-G. Sander§§, T. Scheider§§, T. Schmidt*, D. Schneider*, E. Schneider§, R. Schwarz*, A. Silvestri*, M. Solarz||, G. M. Spiczak†, C. Spliering*, N. Starinsky*, D. Steele*, P. Steffen*, R. G. Stokstad||, O. Streicher*, Q. Sun†, I. Taboada††, L. Thollander†, T. Thon*, S. Tilav*, N. Usechak§, M. Vander Donckt#, C. Walck†, C. Weinheimer§§, C. H. Wiebusch*, R. Wischmewski*, H. Wissing*, K. Woschnagg||, W. Wu§, G. Yodh§ & S. Young§

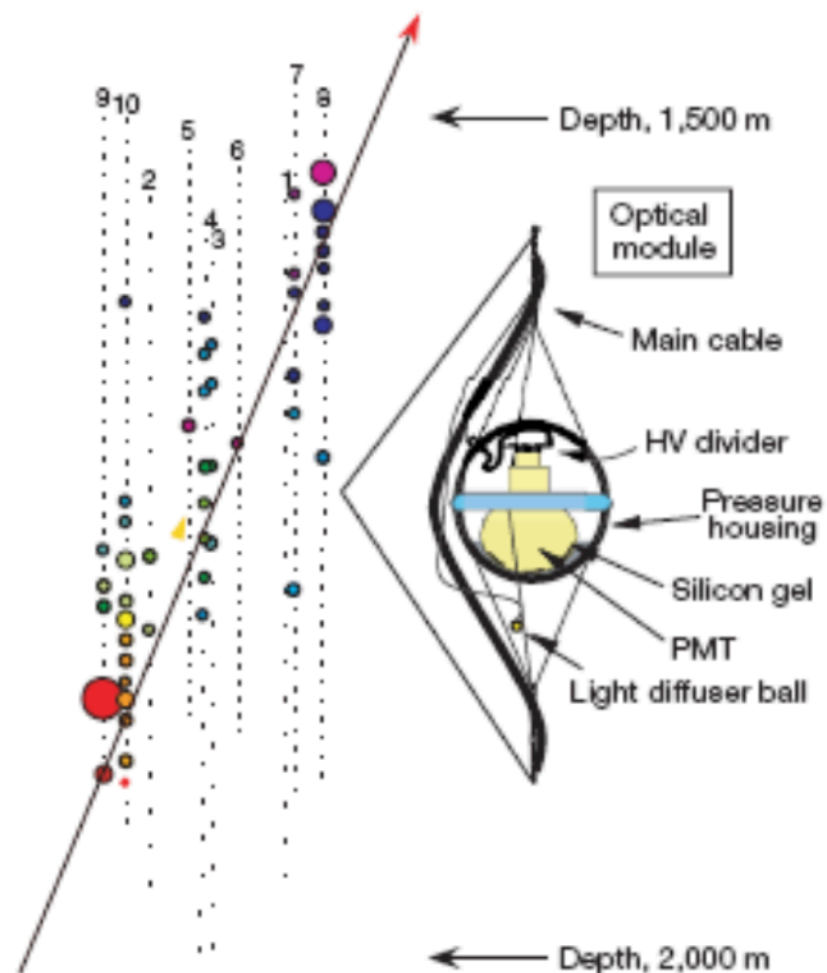
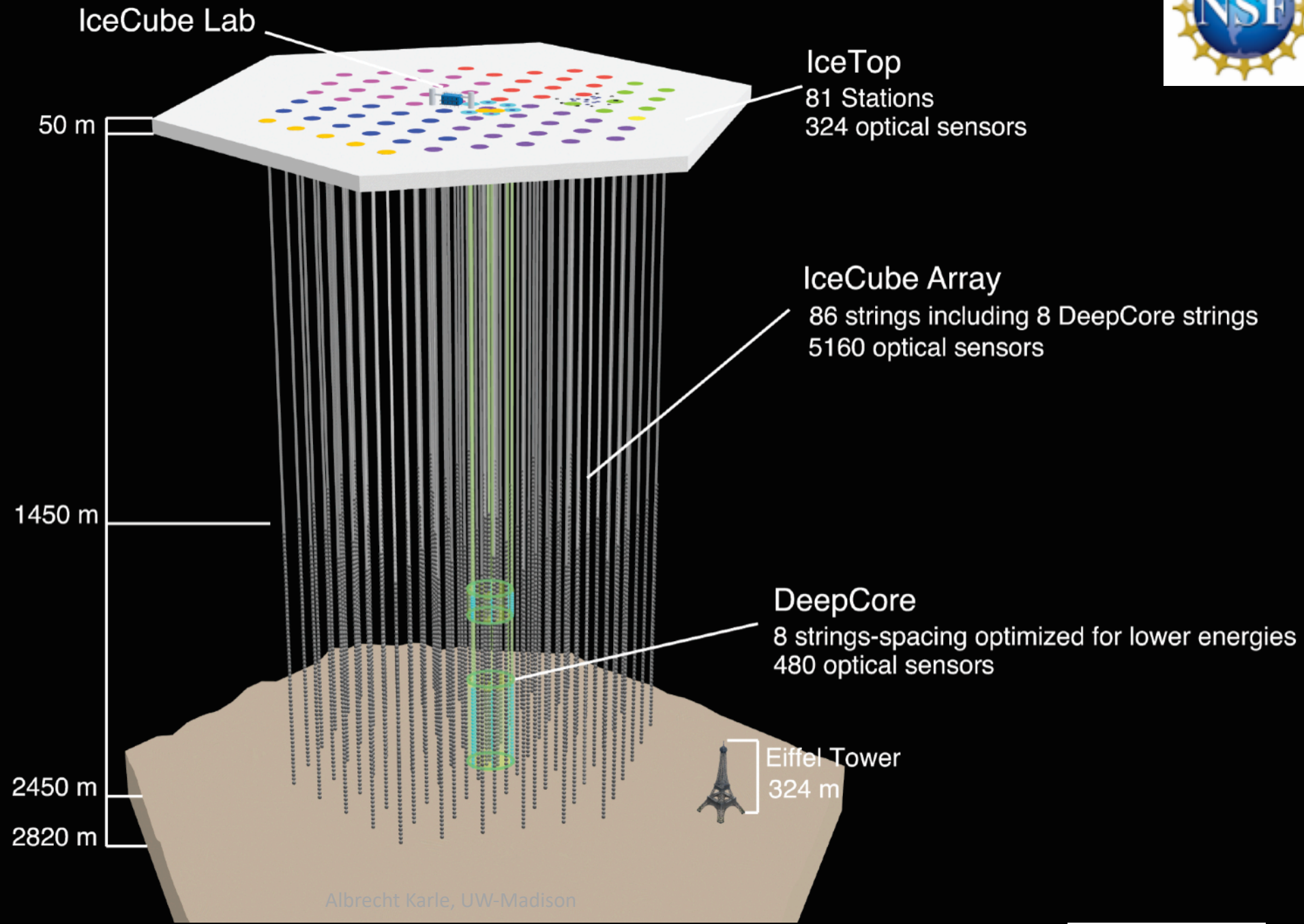


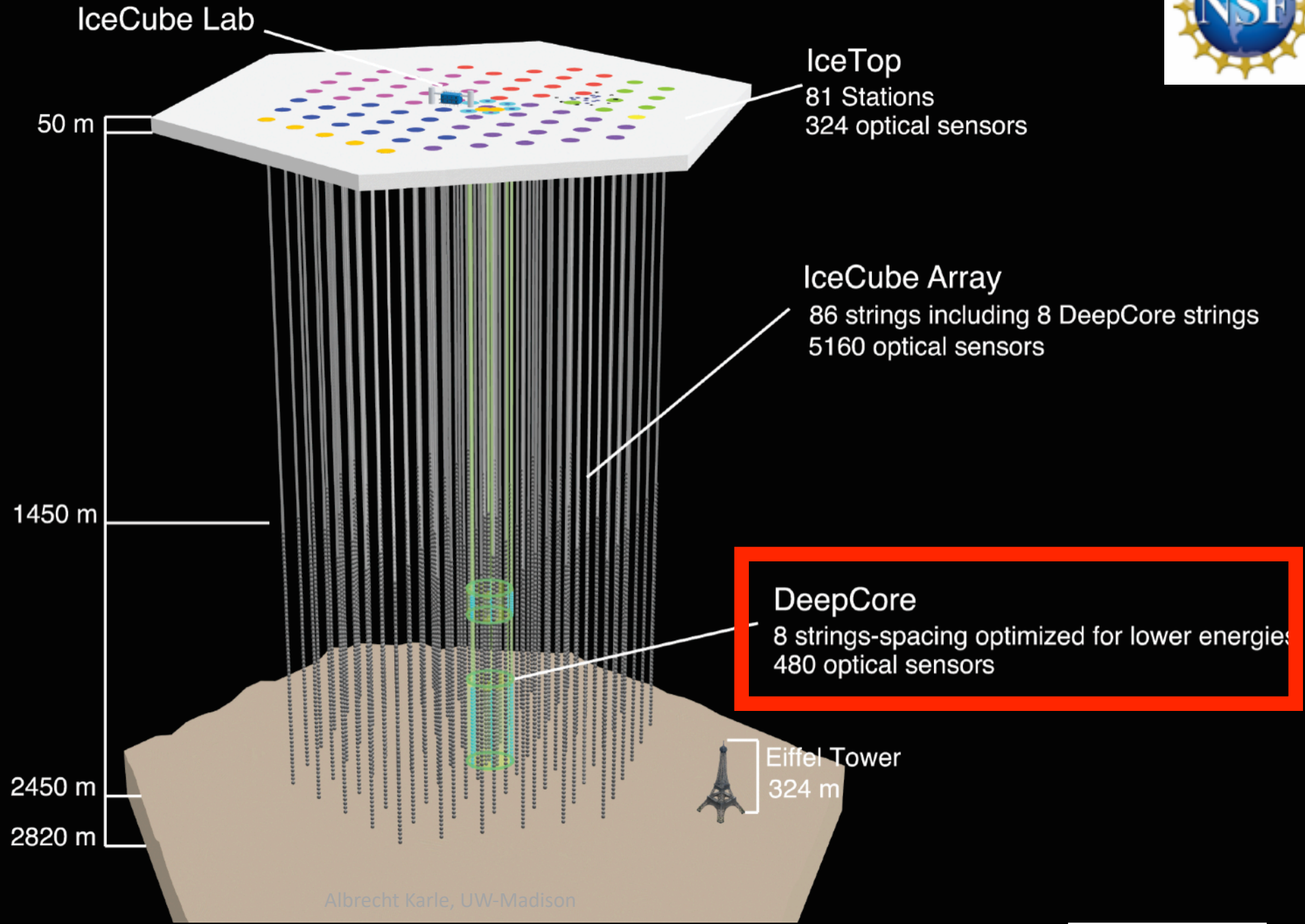
Figure 1 The AMANDA-B10 detector and a schematic diagram of an optical module. Each dot represents an optical module. The modules are separated by 20 m on the inner strings (1 to 4), and by 10 m on the outer strings (5 to 10). The coloured circles show pulses from the photomultipliers for a particular event; the sizes of the circles indicate the amplitudes of the pulses and the colours correspond to the time of a photon's arrival. Earlier times are in red and later ones in blue. The arrow indicates the reconstructed track of the upwardly propagating muon.

In the meantime, AMANDA-II WAS DEPLOYED

The IceCube Neutrino Observatory



The IceCube Neutrino Observatory

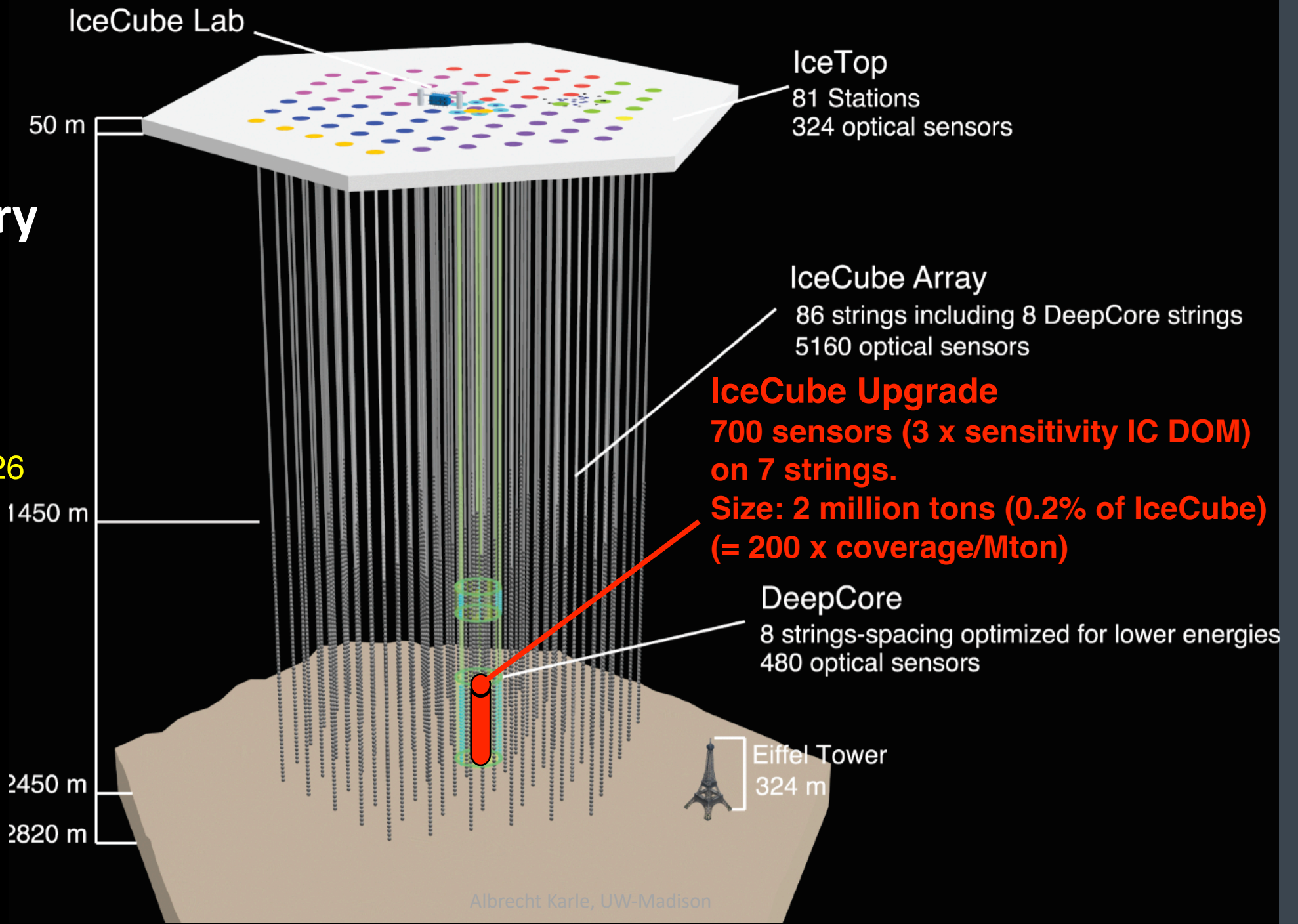


The IceCube Neutrino Observatory

+

IceCube Upgrade

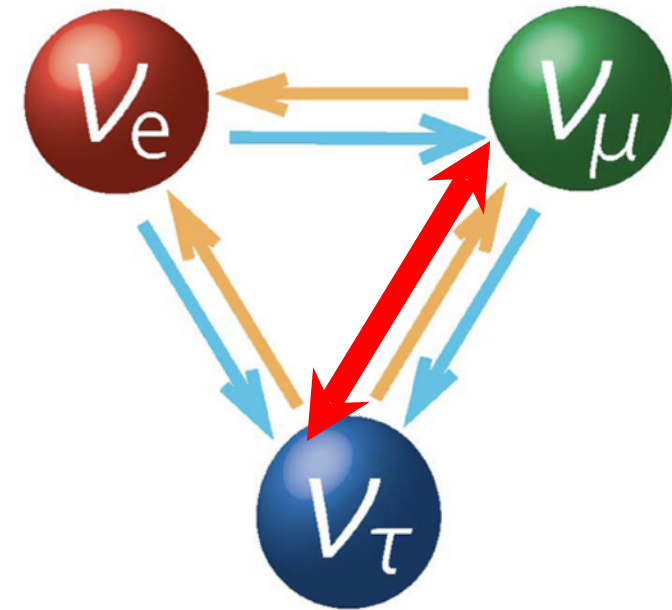
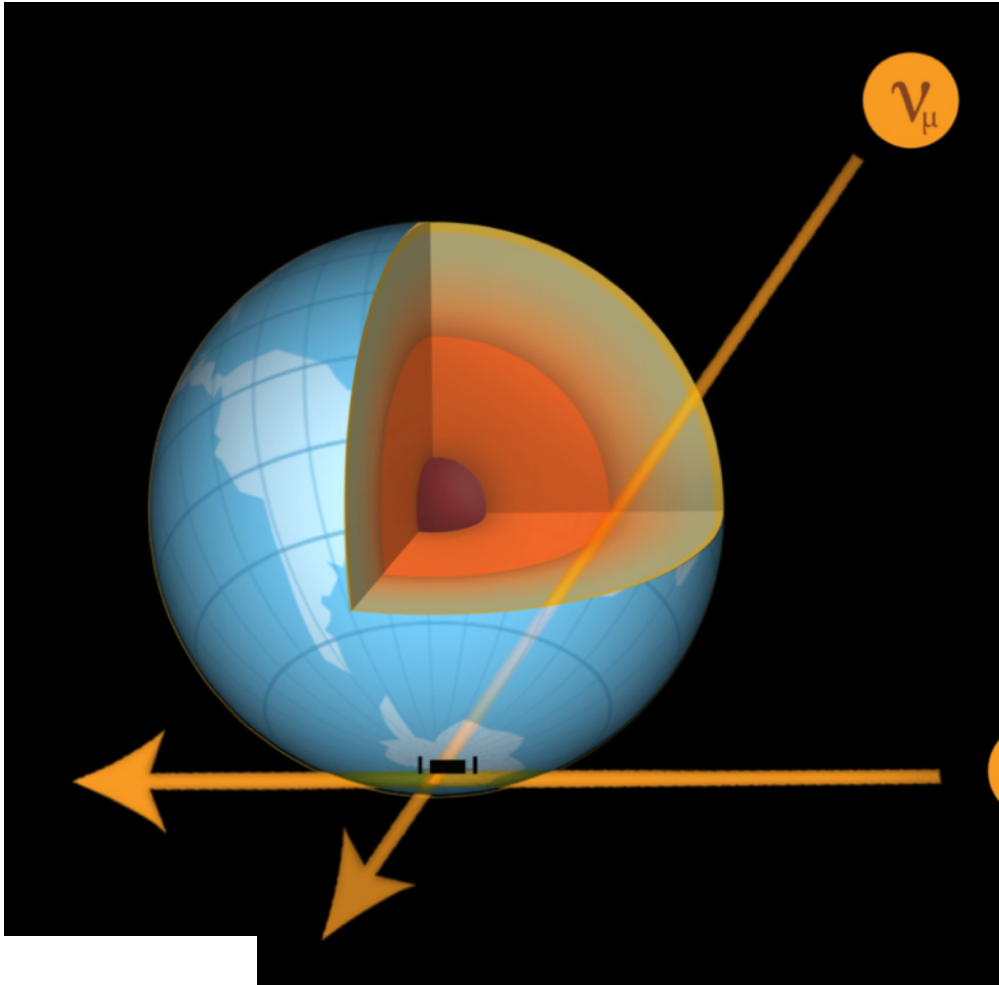
Deploy in 2025/26



Advancing our understanding of neutrino properties

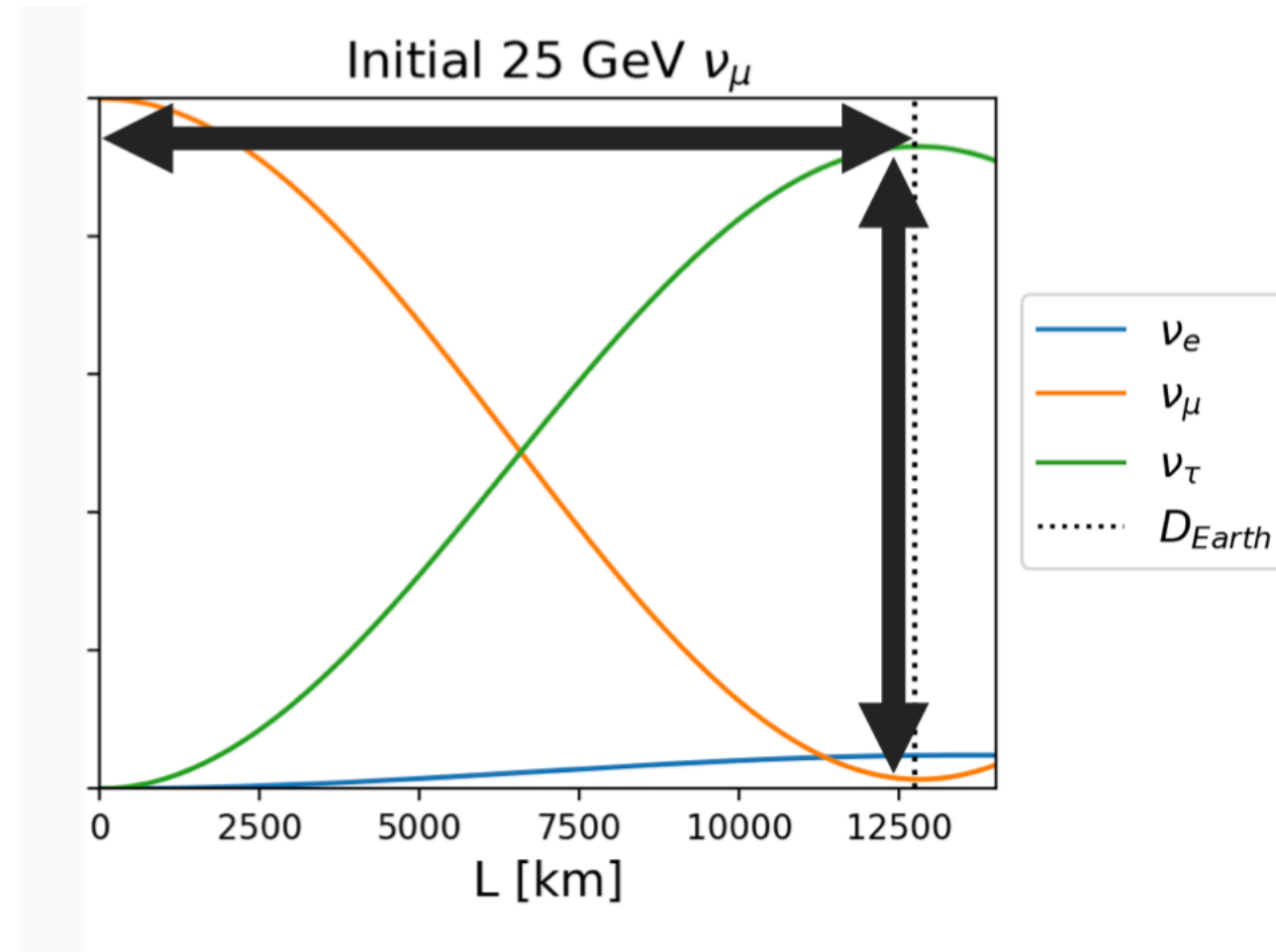
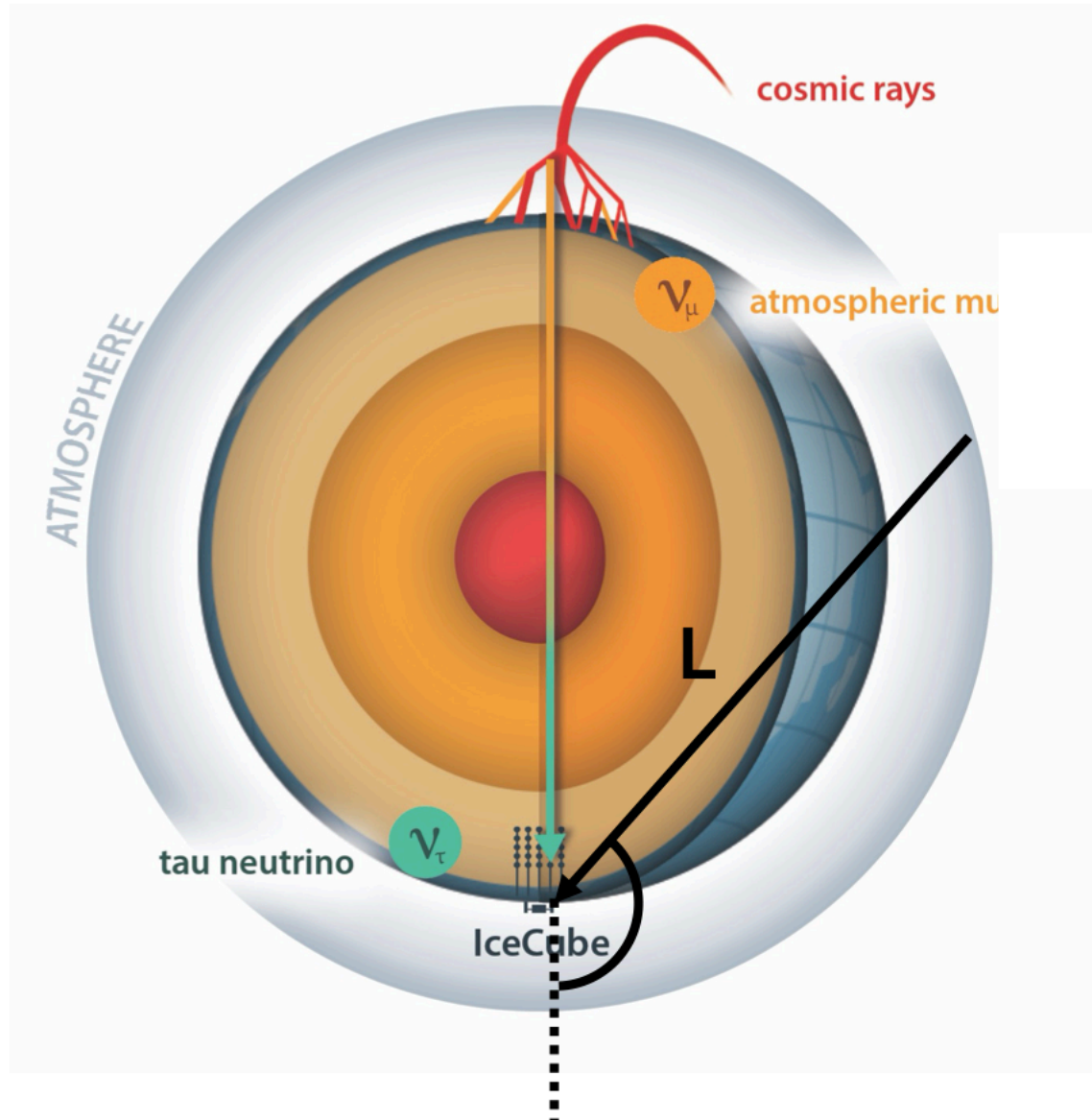
Neutrinos change their identity – their “flavor” – as they travel large distances.

The probability of change depends primarily on energy and distance, to lesser extent on the matter traversed.

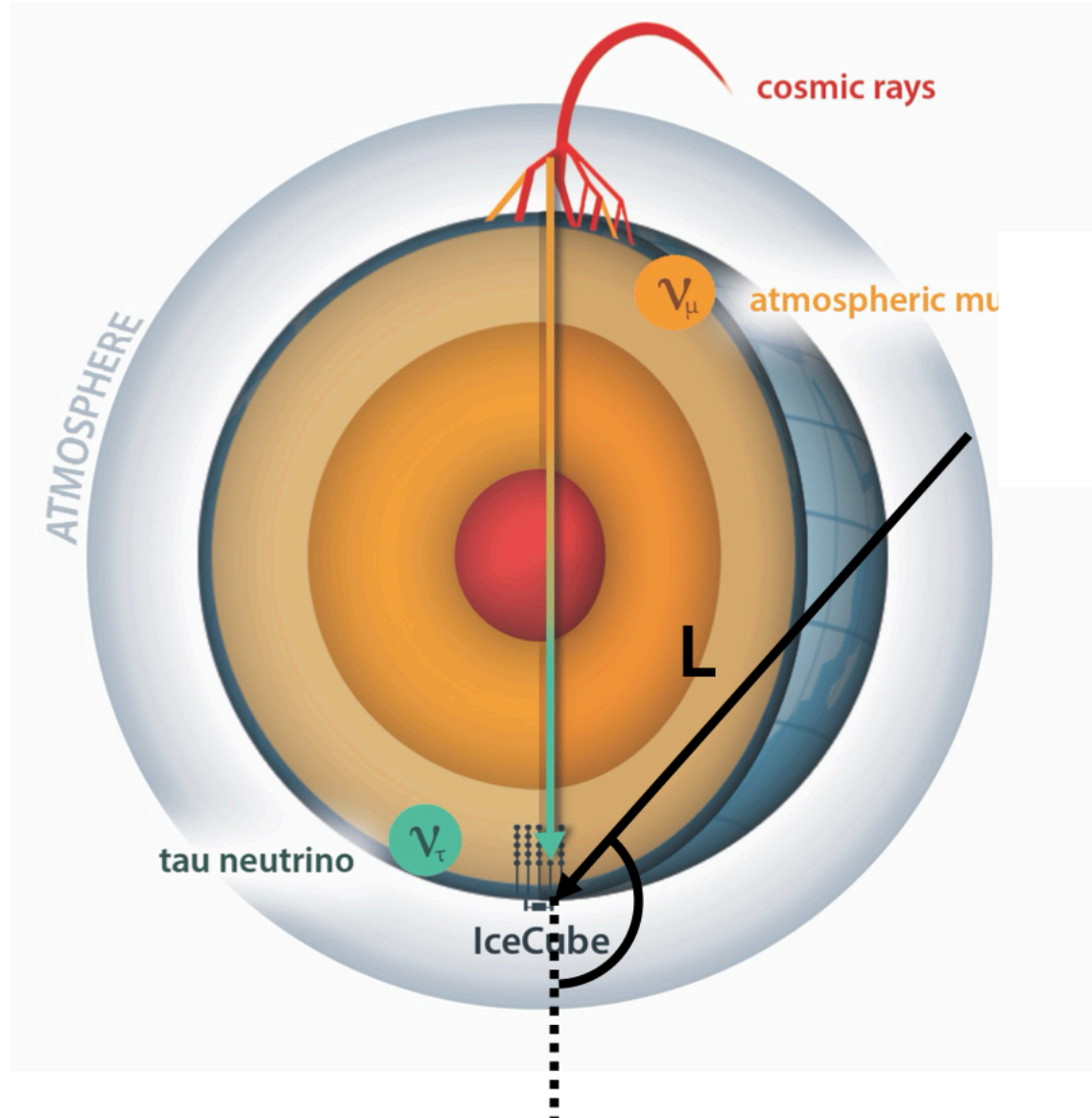


DeepCore: 200,000 events in 10 years.

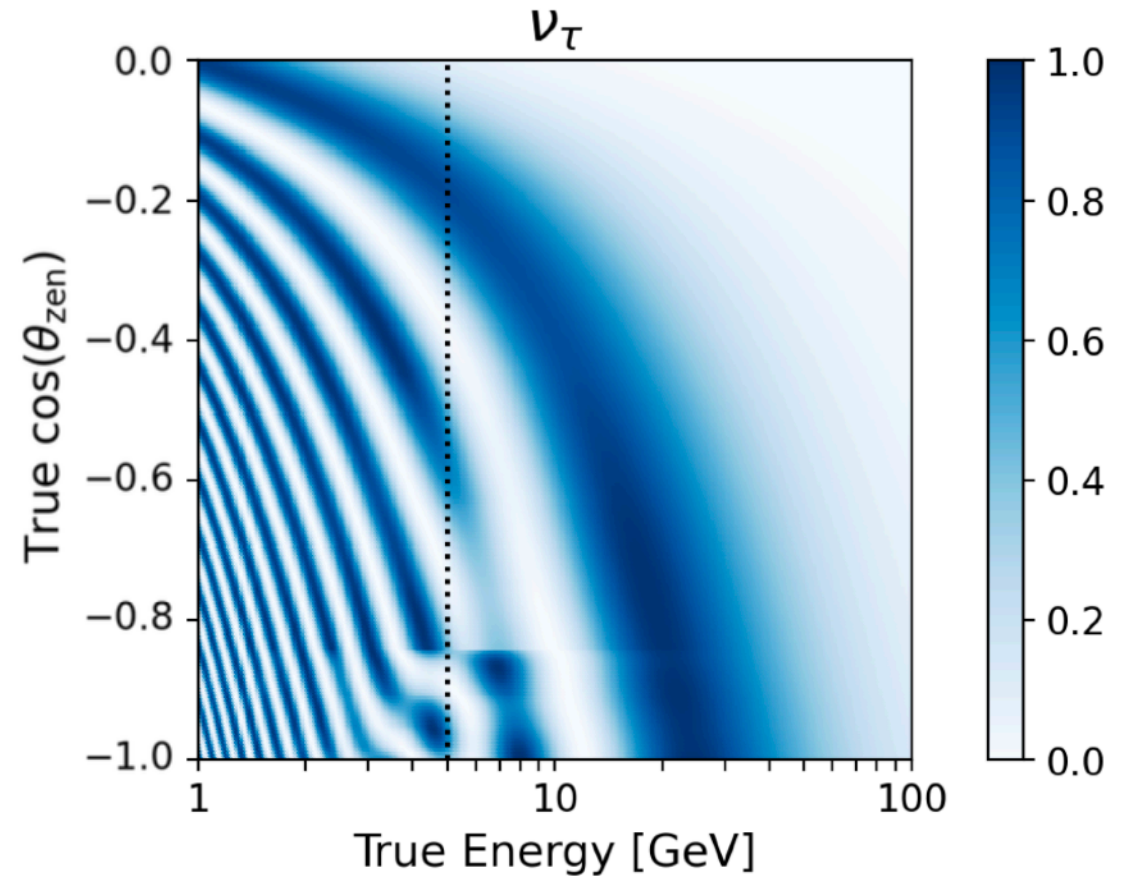
Atmospheric neutrinos as a laboratory:



Atmospheric neutrinos as a laboratory:



Probability for a muon neutrino to emerge as a tau neutrino



DeepCore 
Upgrade 

More Science from the Ice

Astrophysics

- Search for **dark matter**
- Study the cosmic particle accelerators (**transients**)

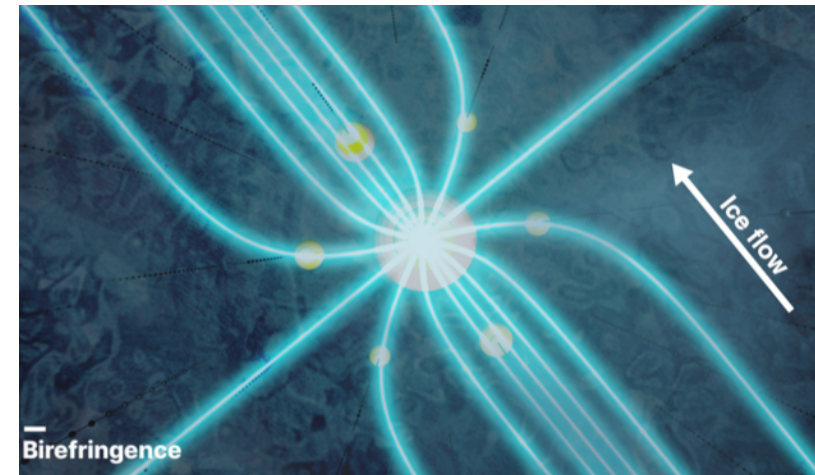
<https://arxiv.org/abs/2605.06600>

R&D for future developments

IceCube-Gen2

The ice is part of the detector

- Precision measurements of the ice's optical properties
- Scattering, absorption, and **birefringence** affect light propagation
- Better understanding of the ice improves neutrino measurements



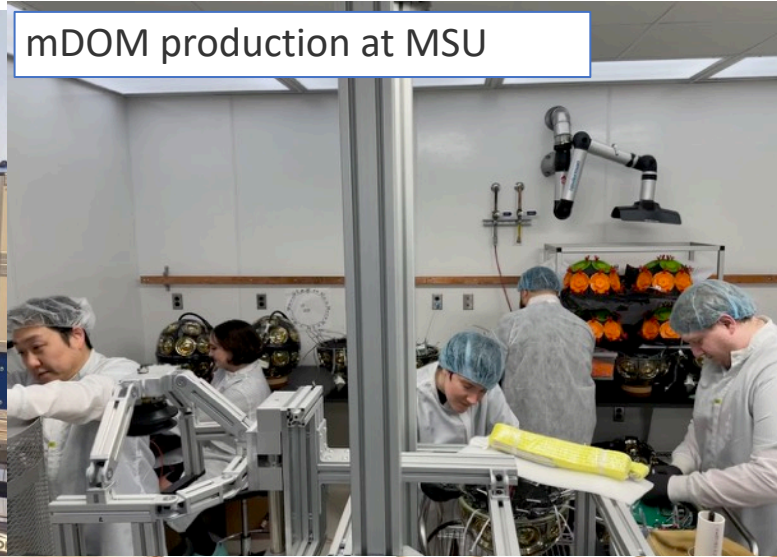
[Abbasi et al. \(IceCube Coll.\), The Cryosphere, 18, 75–102, 2024](#)

Construction

Optical Modules



mDOM production at DESY



mDOM production at MSU



dEgg Production at Chiba



Modules at South Pole!



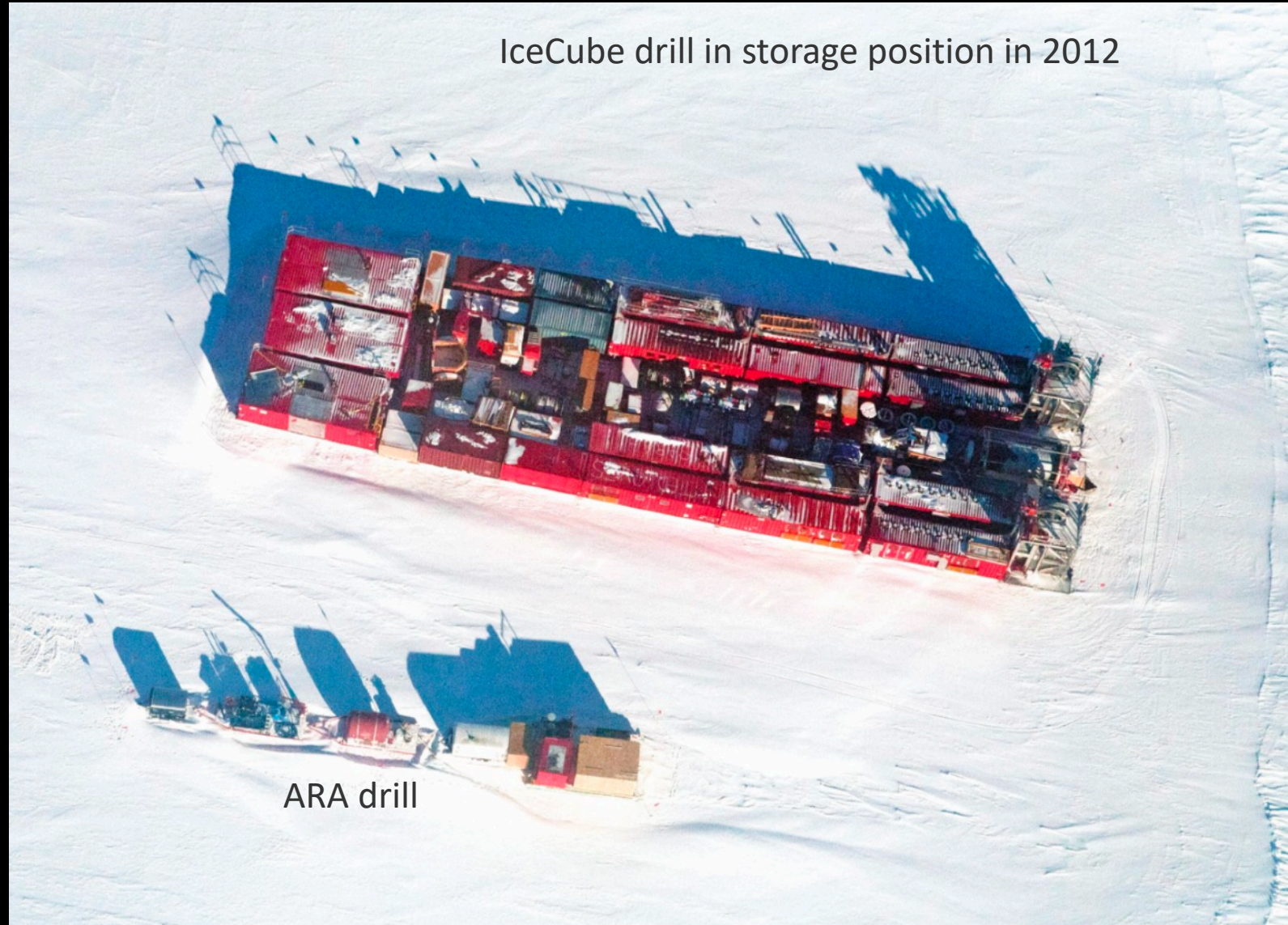
SPAT testing at South Pole

**Most modules arrived at South Pole by 11/23; all modules at South Pole by early December
SPAT testing went smoothly**

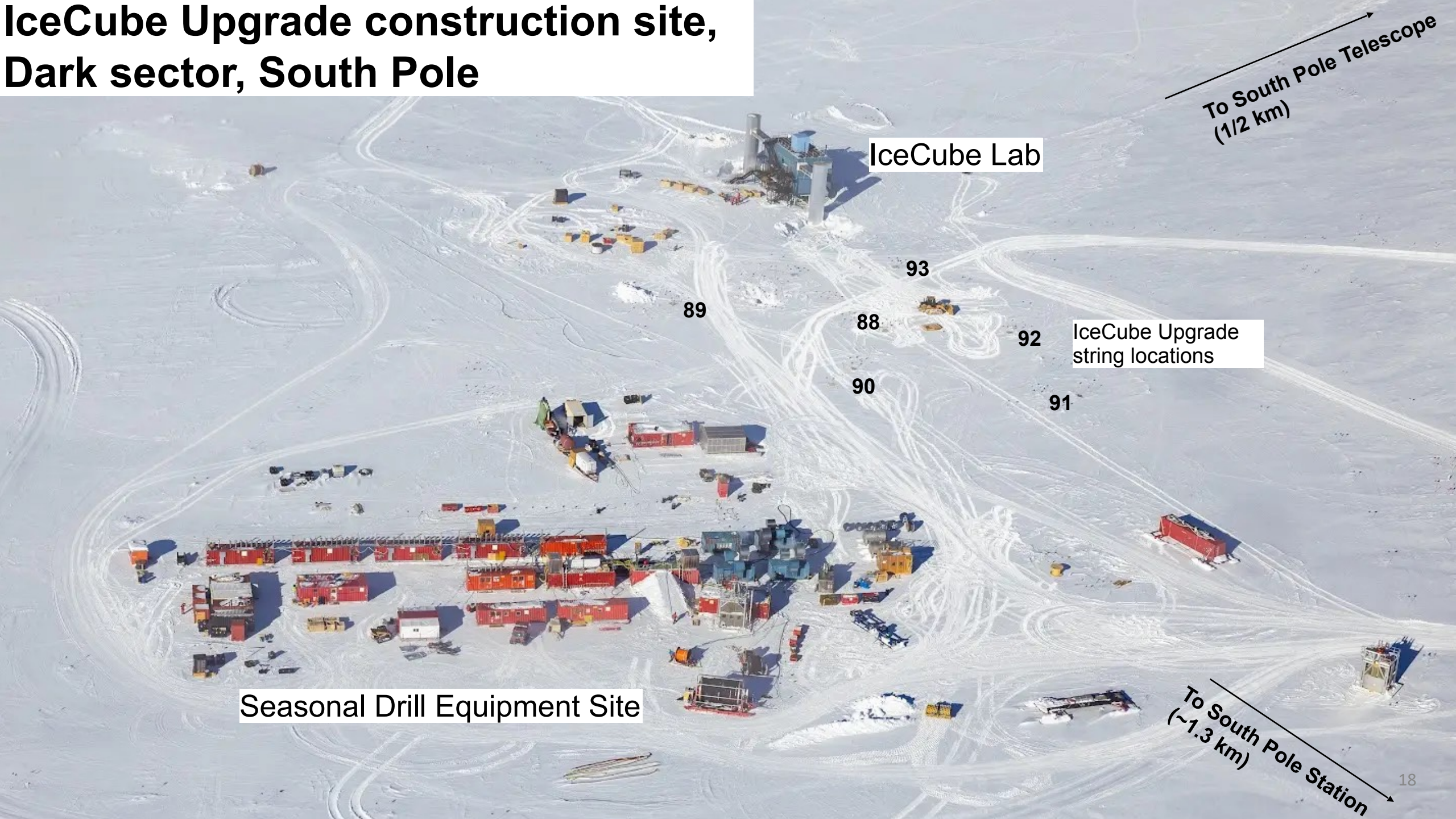
Where is the drill?

The drill had been mothballed after IceCube was completed in 2011.

All electronics and software had to be redone. Everything else was refurbished and brought back to life.



IceCube Upgrade construction site, Dark sector, South Pole



IceCube Lab

To South Pole Telescope
(1/2 km)

IceCube Upgrade
string locations

Seasonal Drill Equipment Site

To South Pole Station
(~1.3 km)

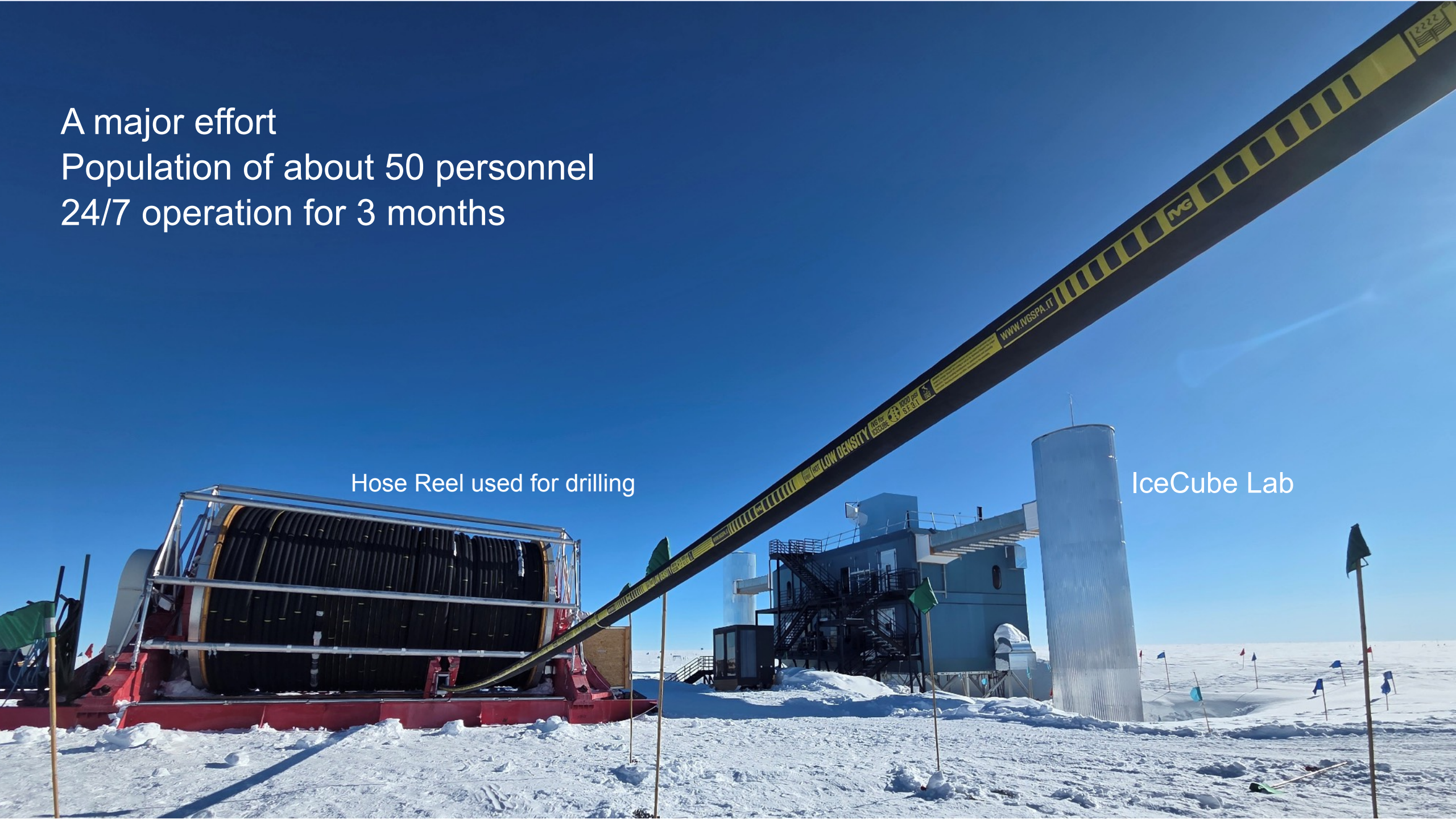
Video: TOS Move to the first string position (87)



A major effort
Population of about 50 personnel
24/7 operation for 3 months

Hose Reel used for drilling

IceCube Lab





Members of the crew work to lower the drill head for the hot-water drill.

Yuya Makino, IceCube/NSF

Logistical Support

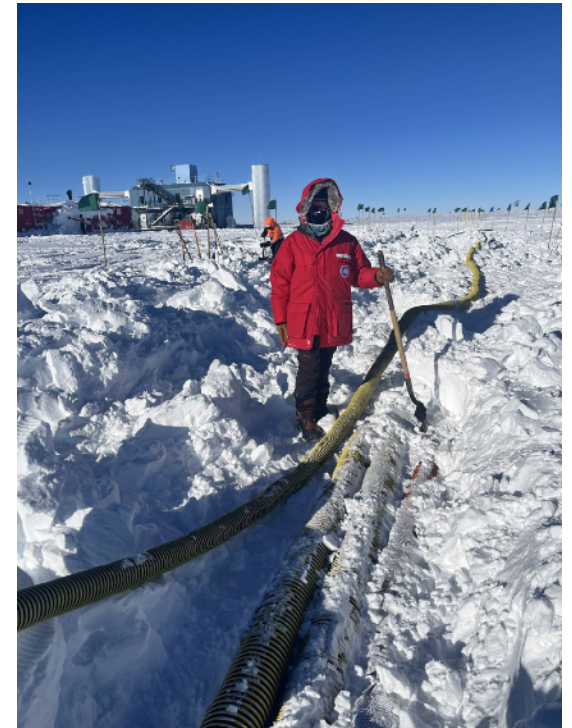
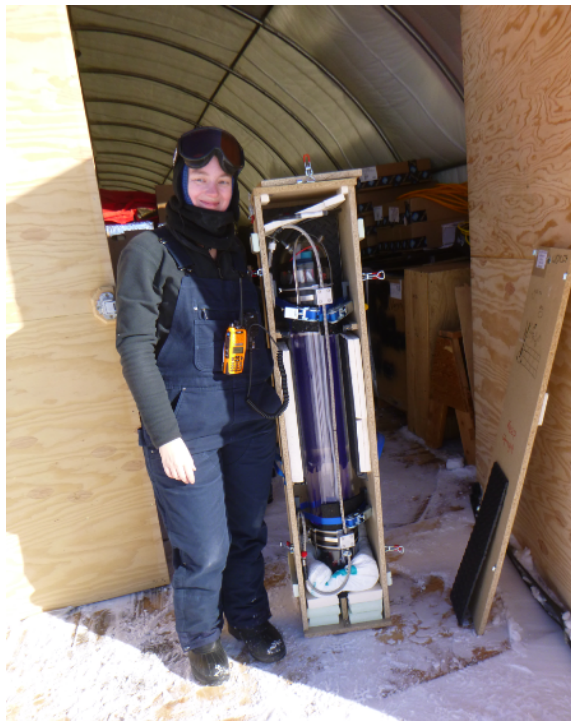
Received outstanding logistical Support by NSF's Office of Polar Programs, through the Antarctic Support Contractor. - Thank You!

Special thank you to all personnel at South Pole Station for their commitment!



Cables arrive with Traverse





Special instruments for calibration and interdisciplinary science:

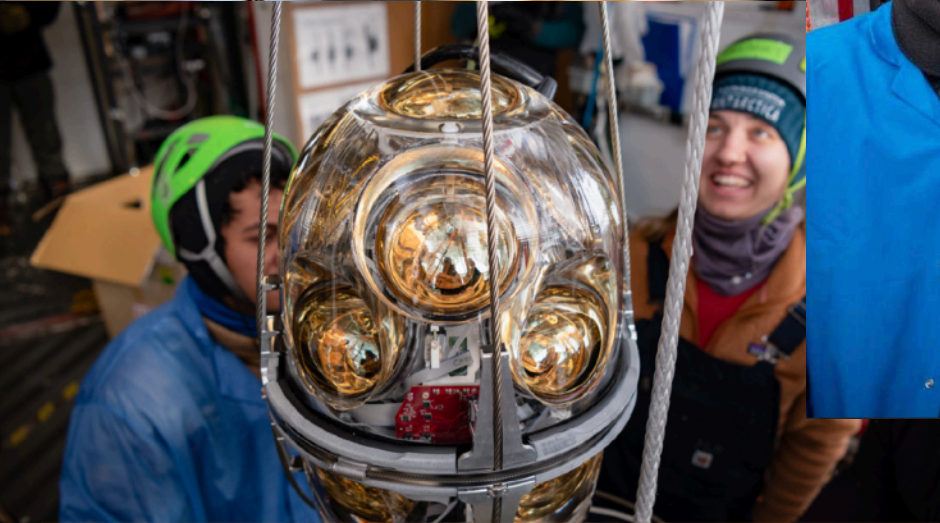
Seismometers
(coll w USGS)



Video cameras



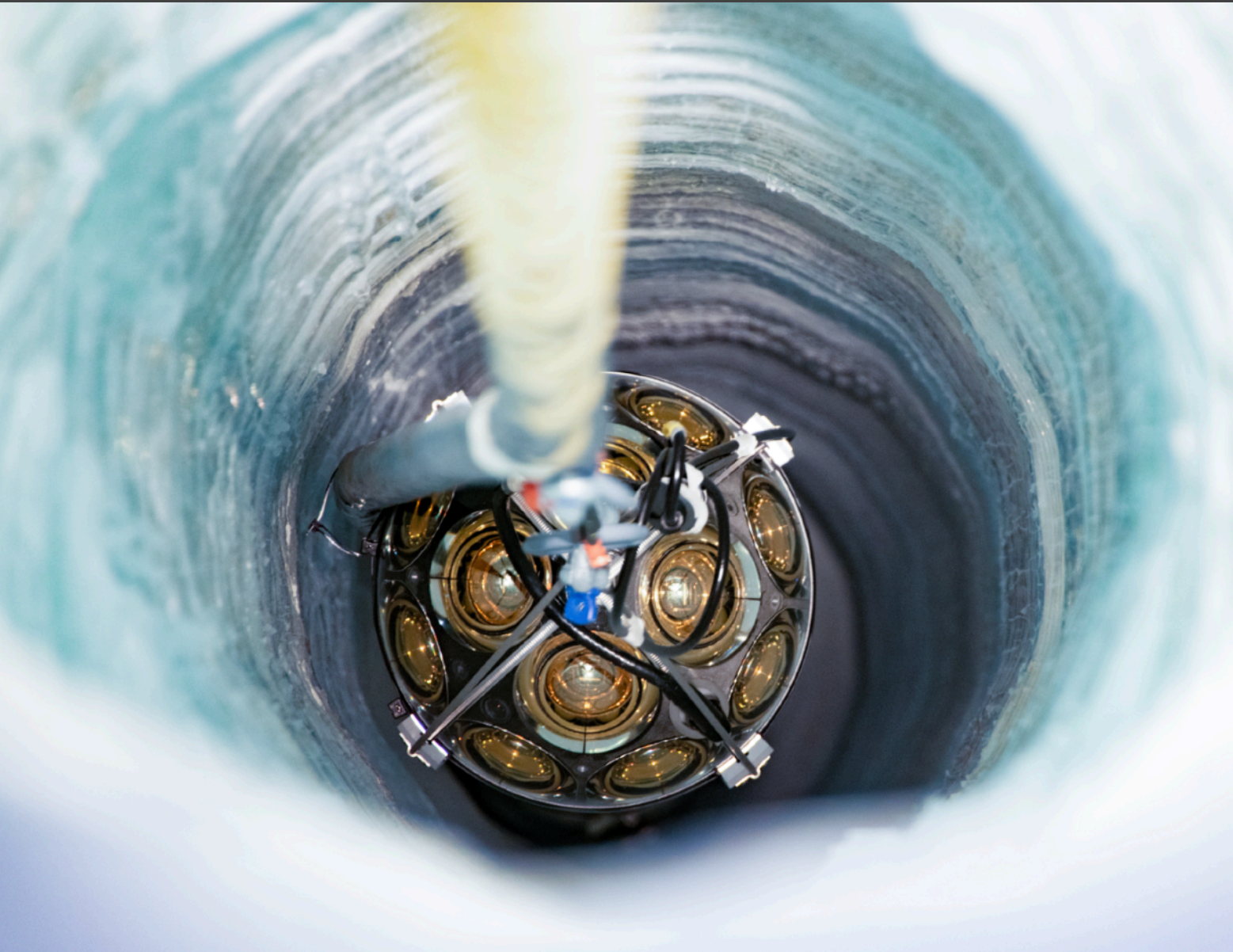
Installation team



New sensor prototype

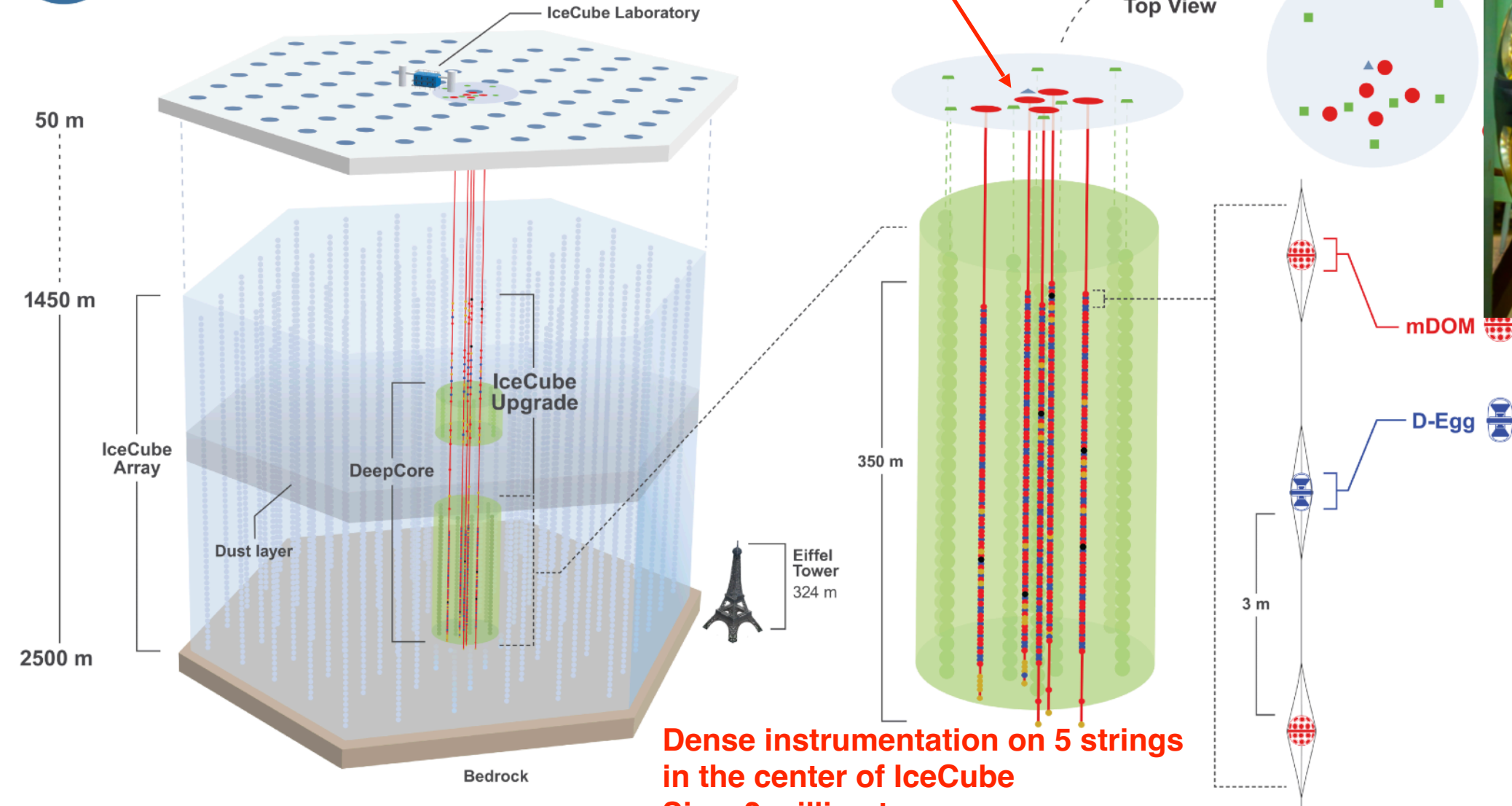


100 sensors were deployed into each borehole





Upgrade sensors strings



**Dense instrumentation on 5 strings
in the center of IceCube**
Size: 2 million tons
—> access to much lower energy
neutrinos (GeV scale)



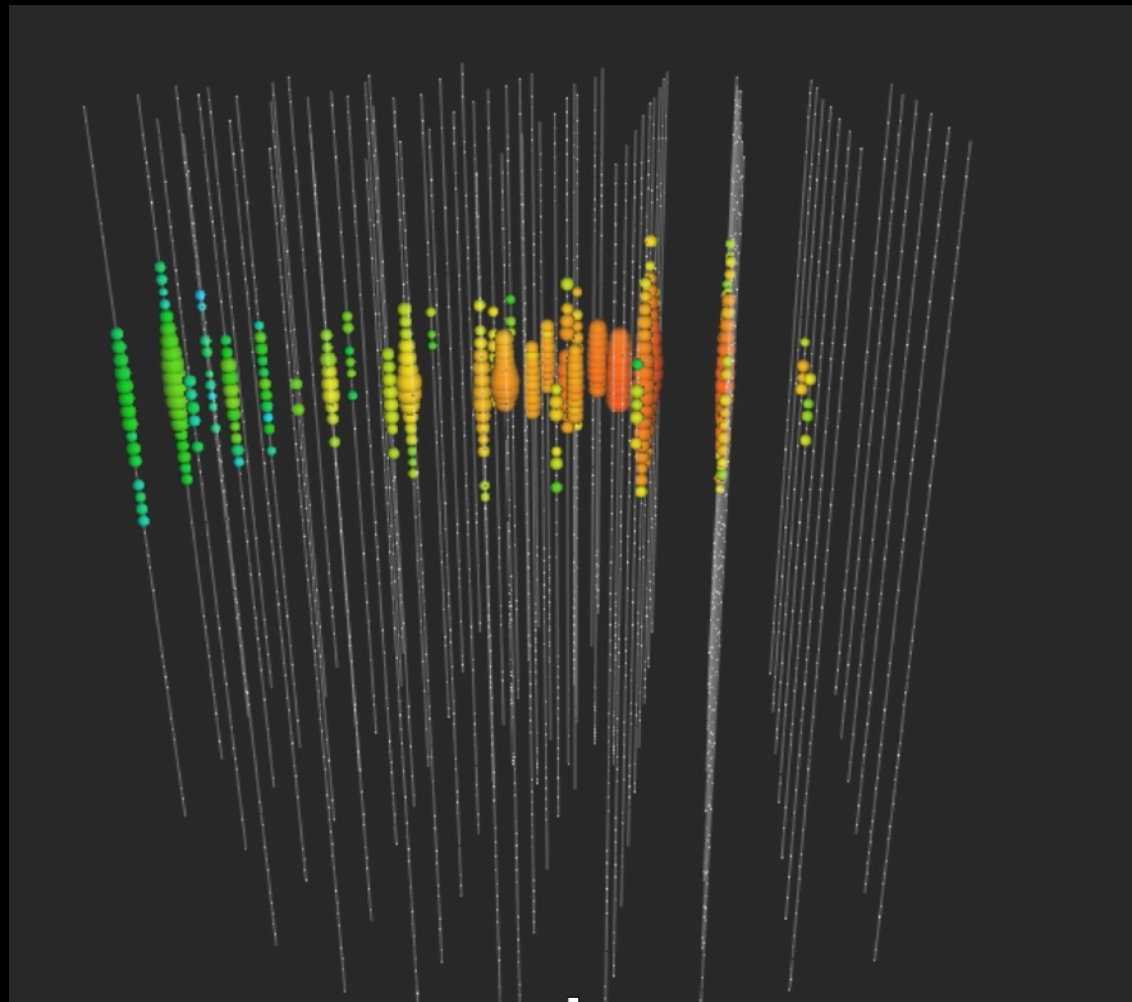
IceCube field team after successful completion

South Pole
January, 2026



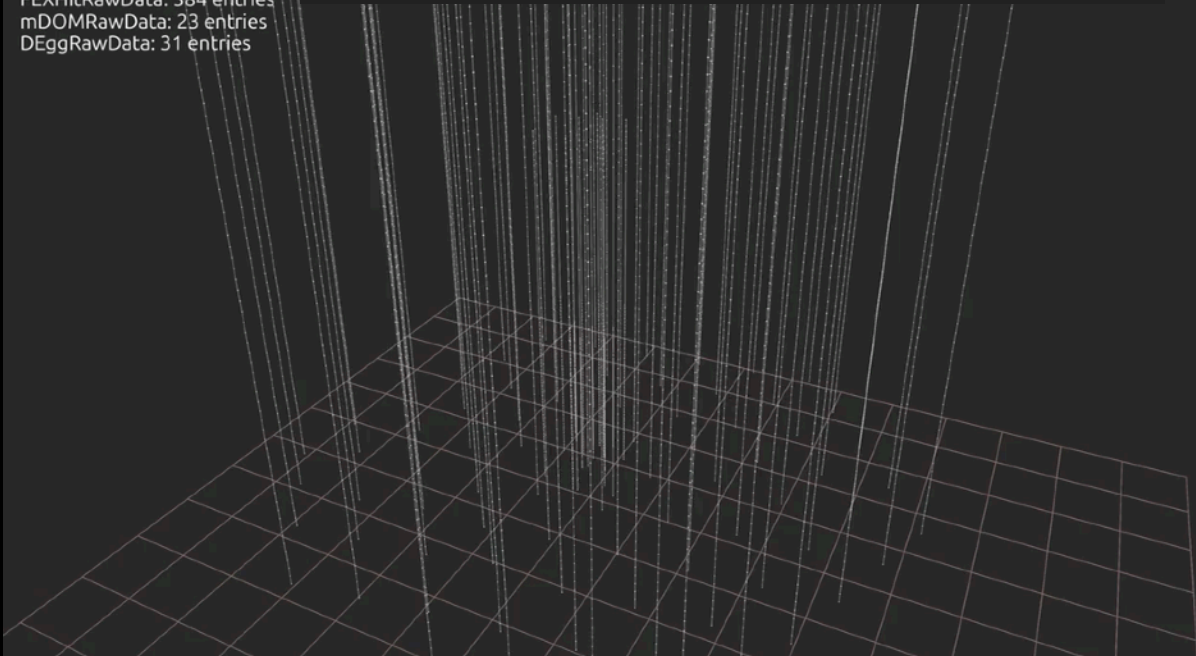
First data and physics outlook

A high energy neutrino event
Energy: ~70 TeV

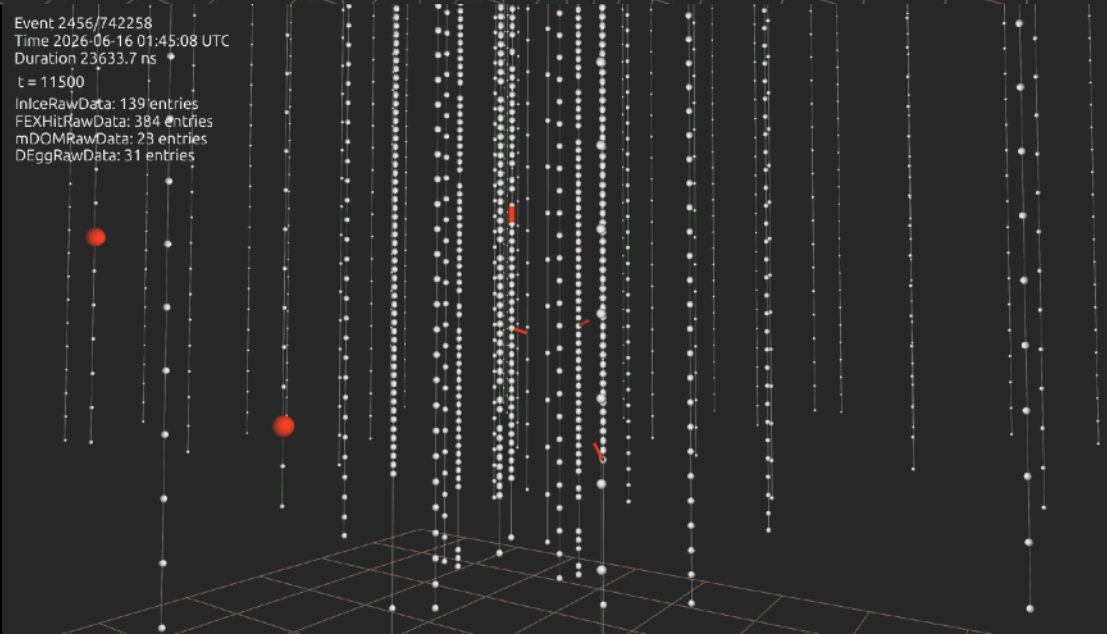


Event 2456/742258
Time 2026-06-16 01:45:08 UTC
Duration 23633.7 ns
t = 6000
InIceRawData: 139 entries
FEXHitRawData: 384 entries
mDOMRawData: 23 entries
DEggRawData: 31 entries

An low event in the IceCube Upgrade
Energy: ~1000 times smaller



Event 2456/742258
Time 2026-06-16 01:45:08 UTC
Duration 23633.7 ns
t = 11500
InIceRawData: 139 entries
FEXHitRawData: 384 entries
mDOMRawData: 23 entries
DEggRawData: 31 entries



Zoomed in:



Noise and Triggerrates

Noise rates:

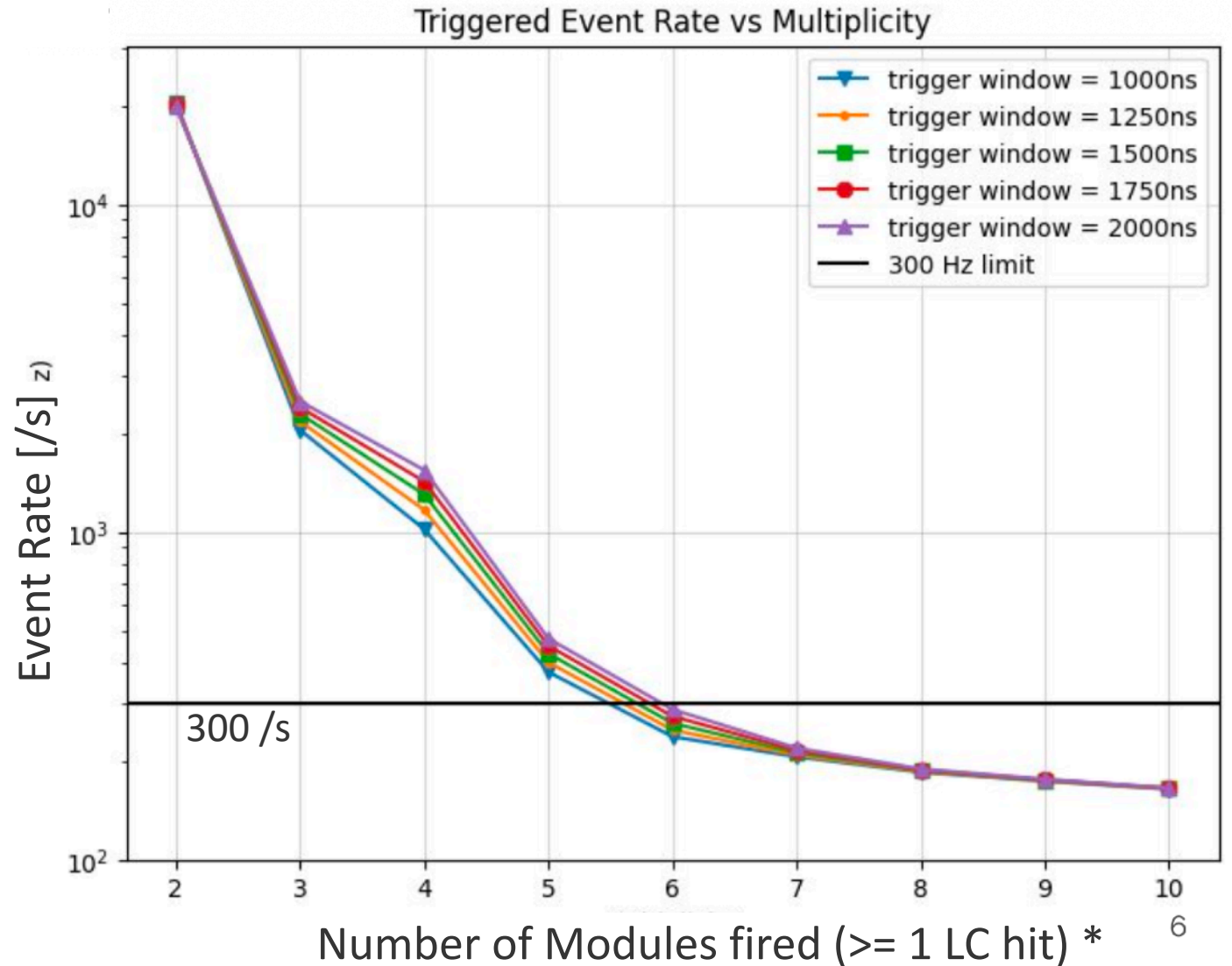
The noise rates are looking very good, lower than projected from lab data. With current settings:

- mDOMs: ~100 Hz / PMT, 2.4kHz / module
- DEggs: ~350 Hz / PMT, 750 Hz / module

(South Pole ice is exceptionally pure. Noise background comes from cosmic ray muons.)

Trigger rate:

One can see the transition from noise events to events that are caused by physics events, eg. muons at around.



Noise and Trigger rates

Noise rates:

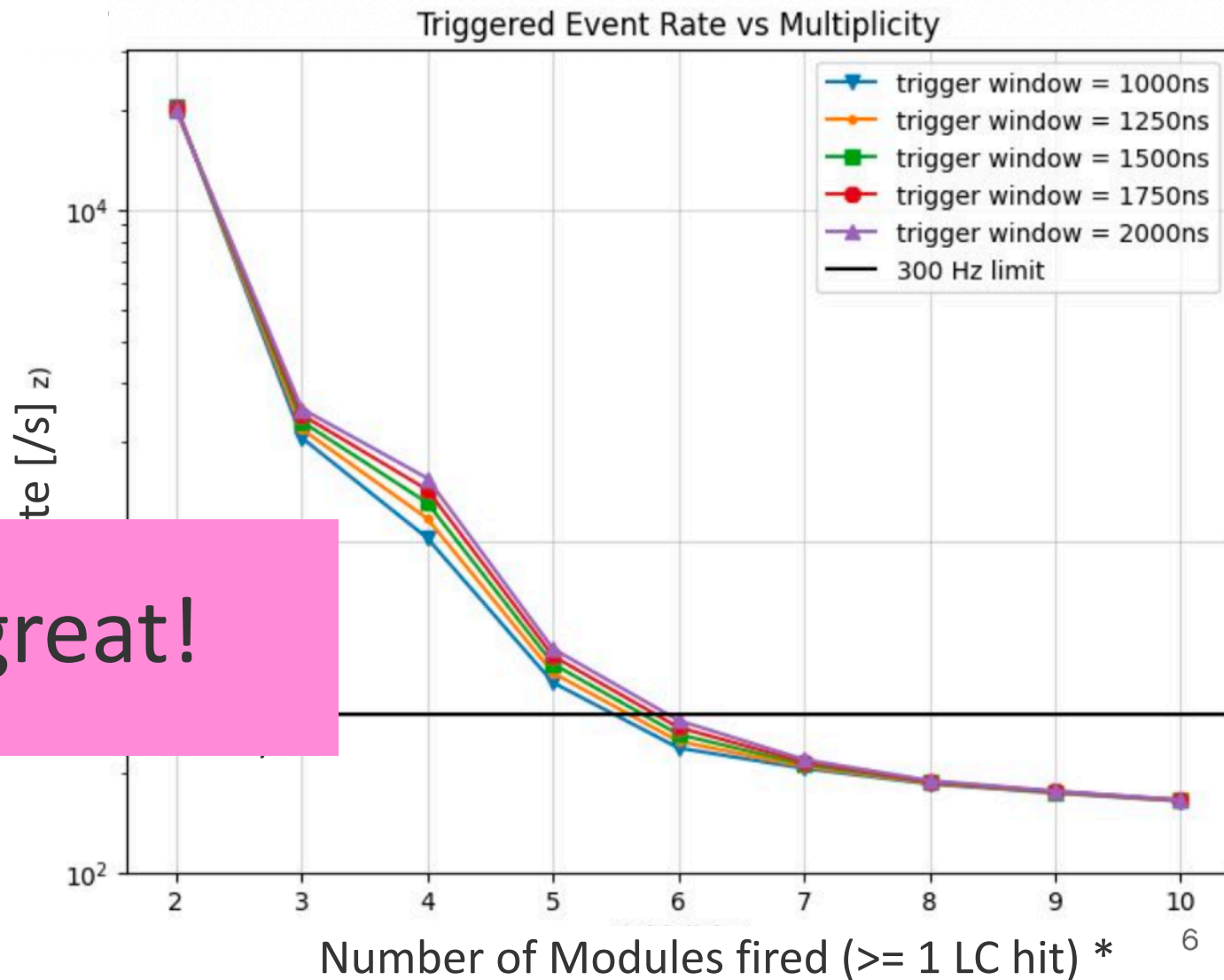
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(South Pole ice is exceptionally pure. Noise

Everything is looking great!

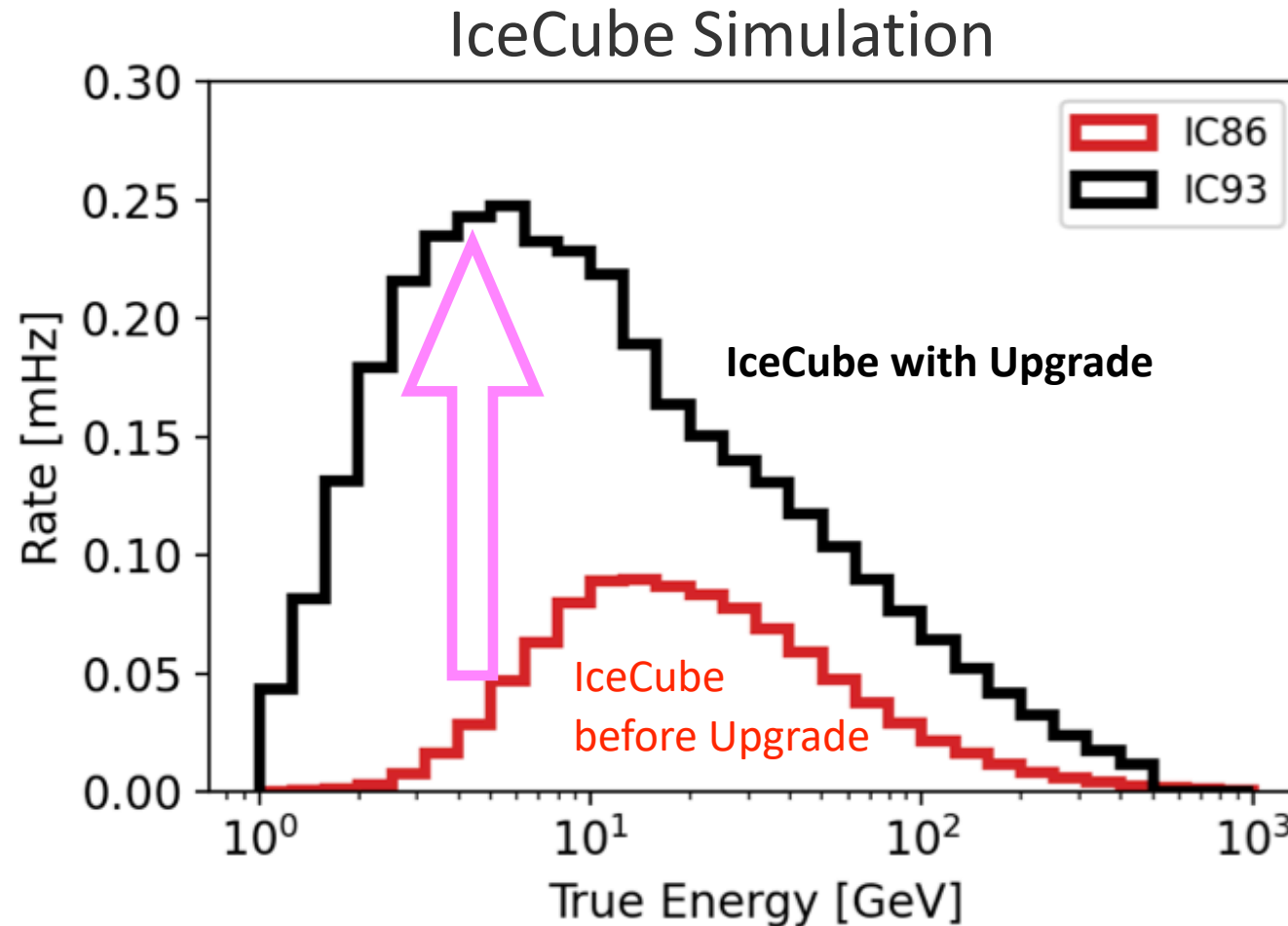
noise events to events that are caused by physics events, eg. muons at around.



Final level energy distribution

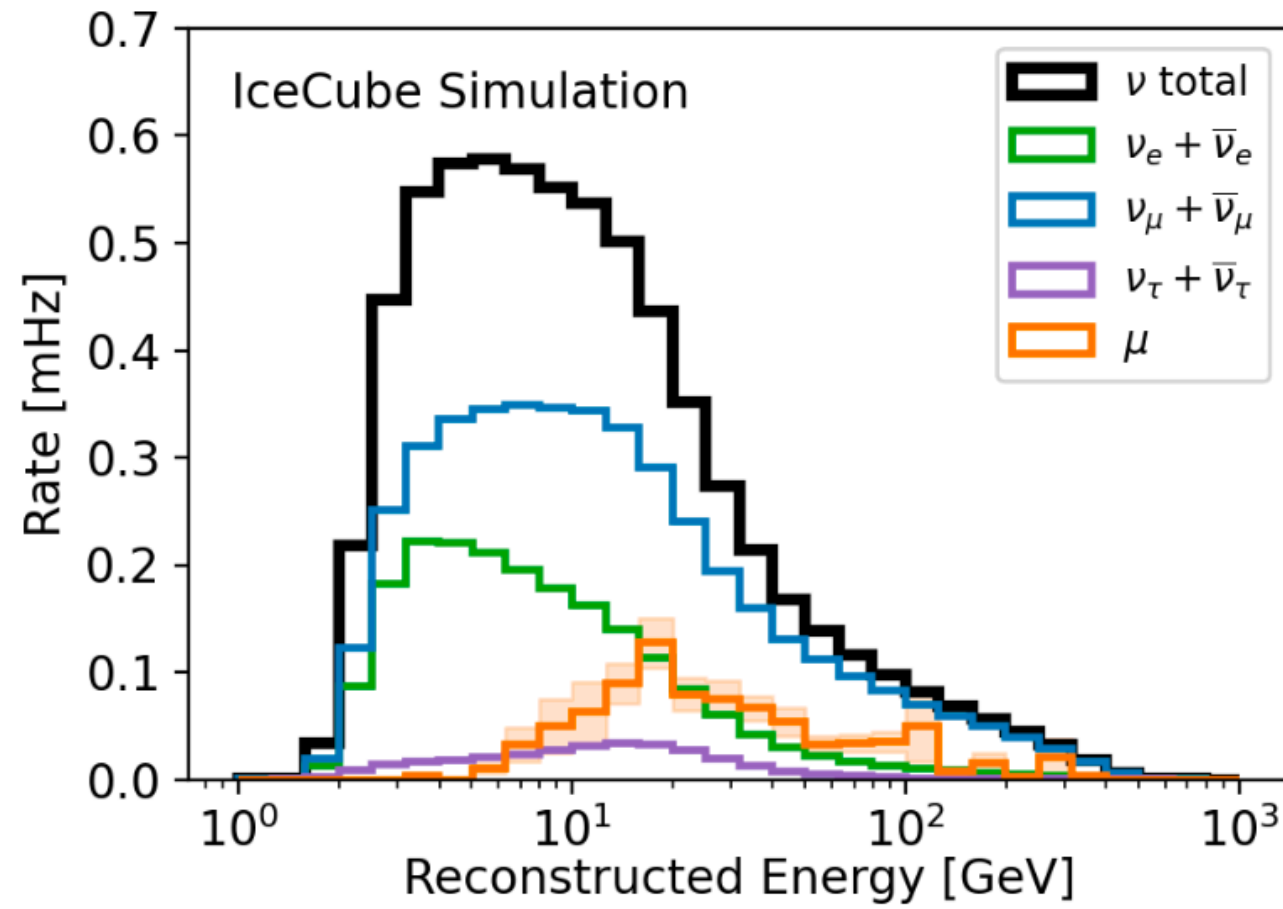
Huge gain in event rates below 10 GeV

Upgrade: $> 100,000$ neutrinos per year (target mass of order 2 Mtons)



Neutrino event rates, by flavor

arXiv: 2509.13066v1



Science

- Physics potential of the IceCube Upgrade for **atmospheric neutrino oscillations** published

<https://arxiv.org/pdf/2509.13066>

- **Astrophysical** Sensitivity Projections for the IceCube Upgrade

<https://arxiv.org/pdf/2605.06600>

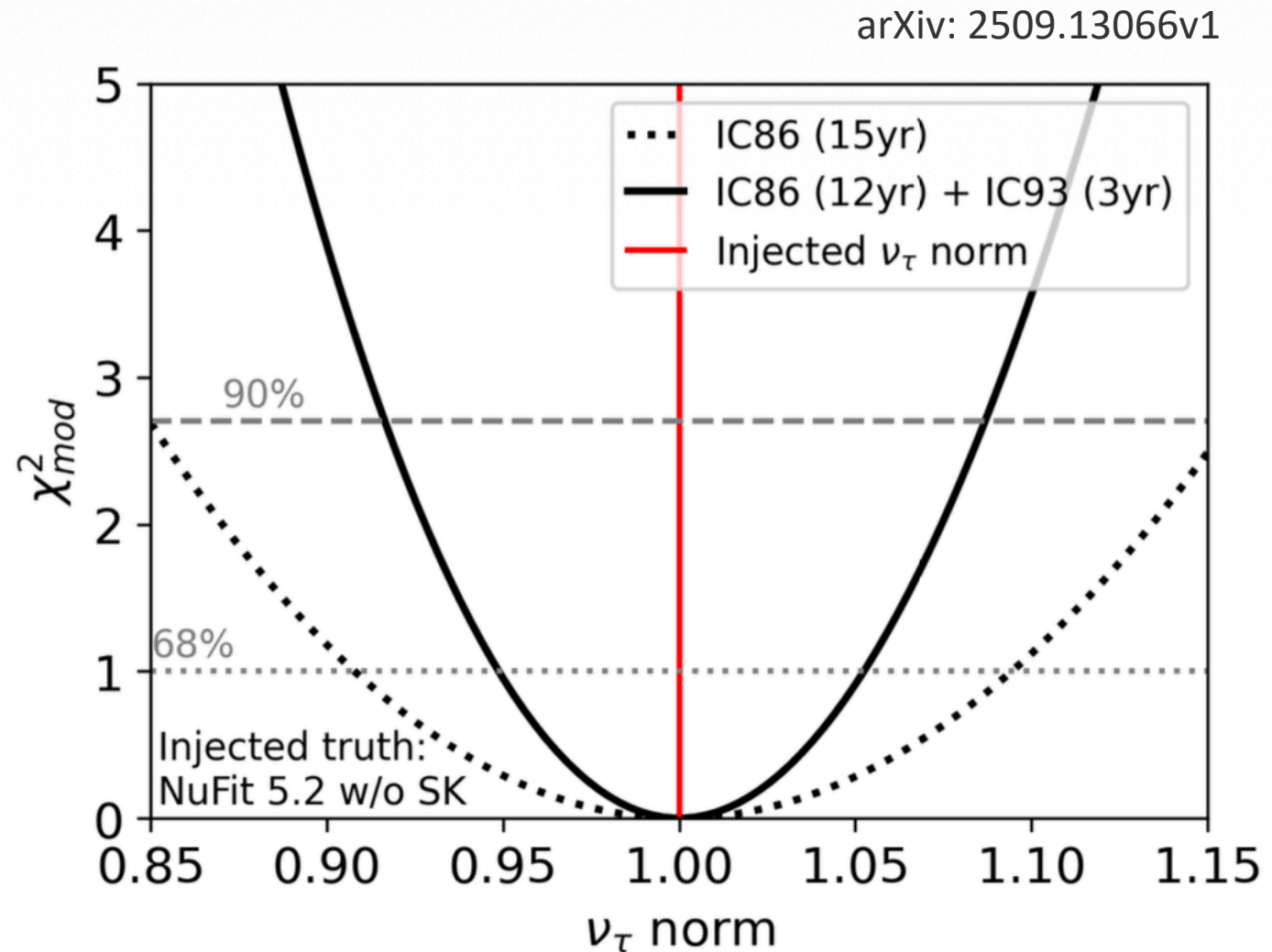
- Sensitivity Projections for Low-Mass **Dark Matter** Annihilation with the IceCube Upgrade

<https://arxiv.org/pdf/2605.06600>

Sensitivity to tau neutrino flux normalization



After three years of Upgrade data added, comparison to current results.

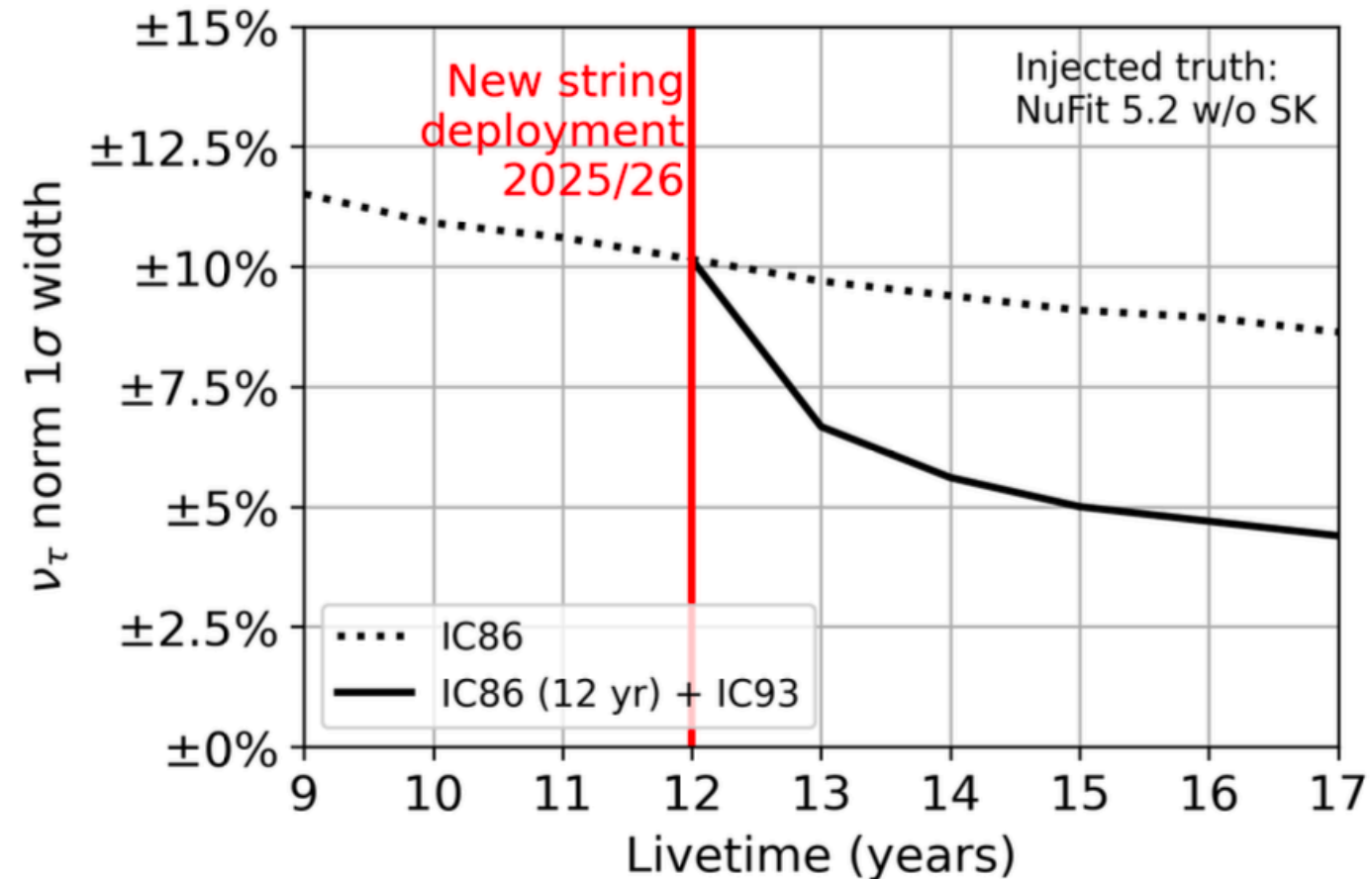


Sensitivity to tau neutrino flux normalization



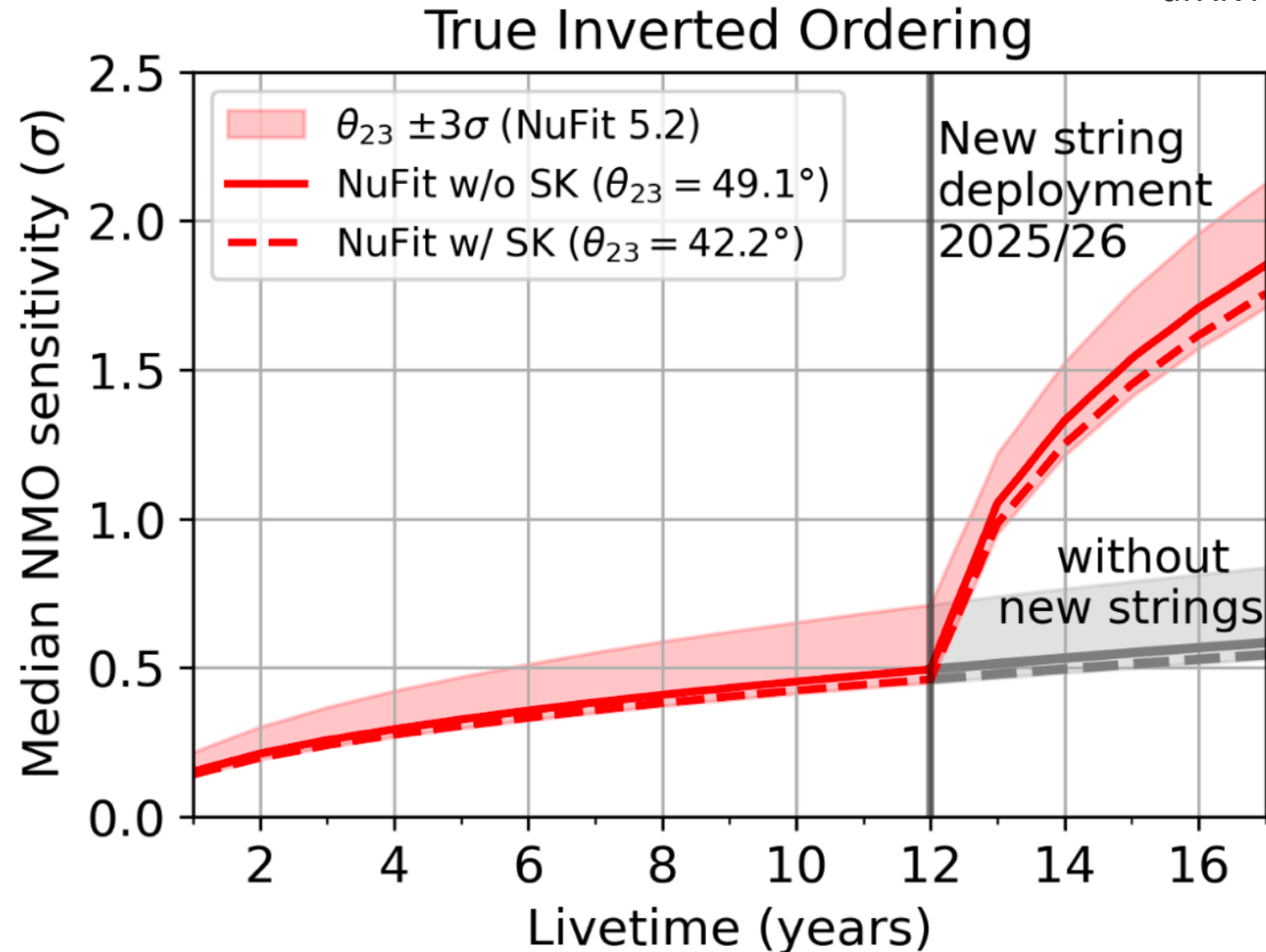
arXiv: 2509.13066v1

After three years of Upgrade data added, comparison to projection without the Upgrade.



Sensitivity to neutrino mass ordering

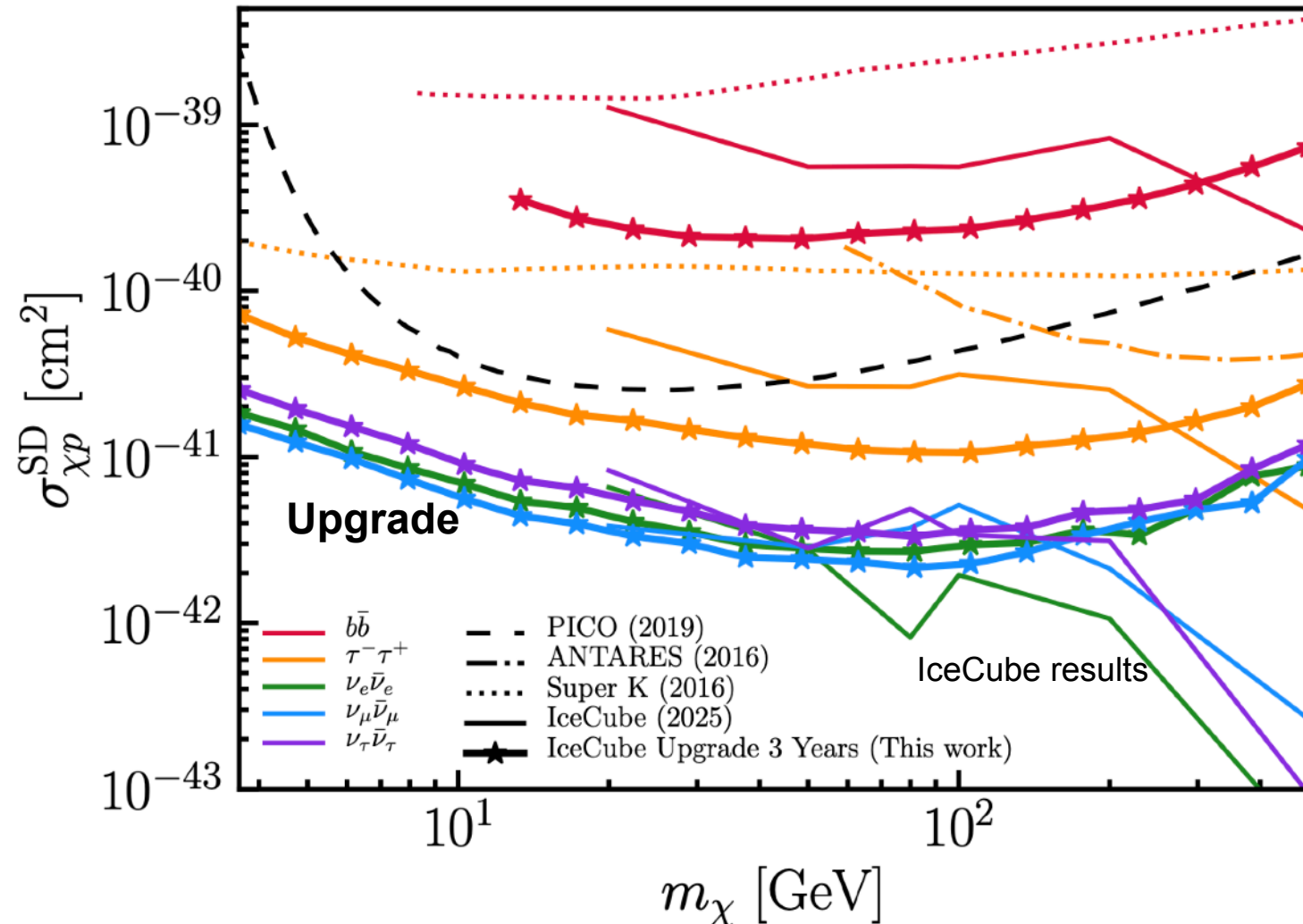
After three years of Upgrade data added, comparison to projection without the Upgrade.



Sensitivity to WIMPs from the sun

<https://arxiv.org/pdf/2605.06600>

After three years of Upgrade data added, comparison to current results.
- Spin dependent DM-proton interactions



IceCube got an Upgrade!
Thank you to everyone who helped
over the course of more than 7 years,
including our ASC friends at the South Pole
Station and the funding agencies.



Acknowledgements



Takeaway:

- **Completed the installation successfully** in January 2026
- **Optical sensors are performing very well.**
- New laboratory for **neutrino and astrophysics.**
- The as-built detector is projected to **meet its science goals.**
- Exciting Science ahead!
- **Thank you for more than 2 decades of very successful collaboration with Chiba University!**

Thank you!



This well-fed penguin decided to stay there all day, right in the middle of McMurdo.