The IceCube Upgrade: status and prospects for new advances with GeV neutrinos

Neutrino Physics

Nora Feigl

Prague, 18. July 2024

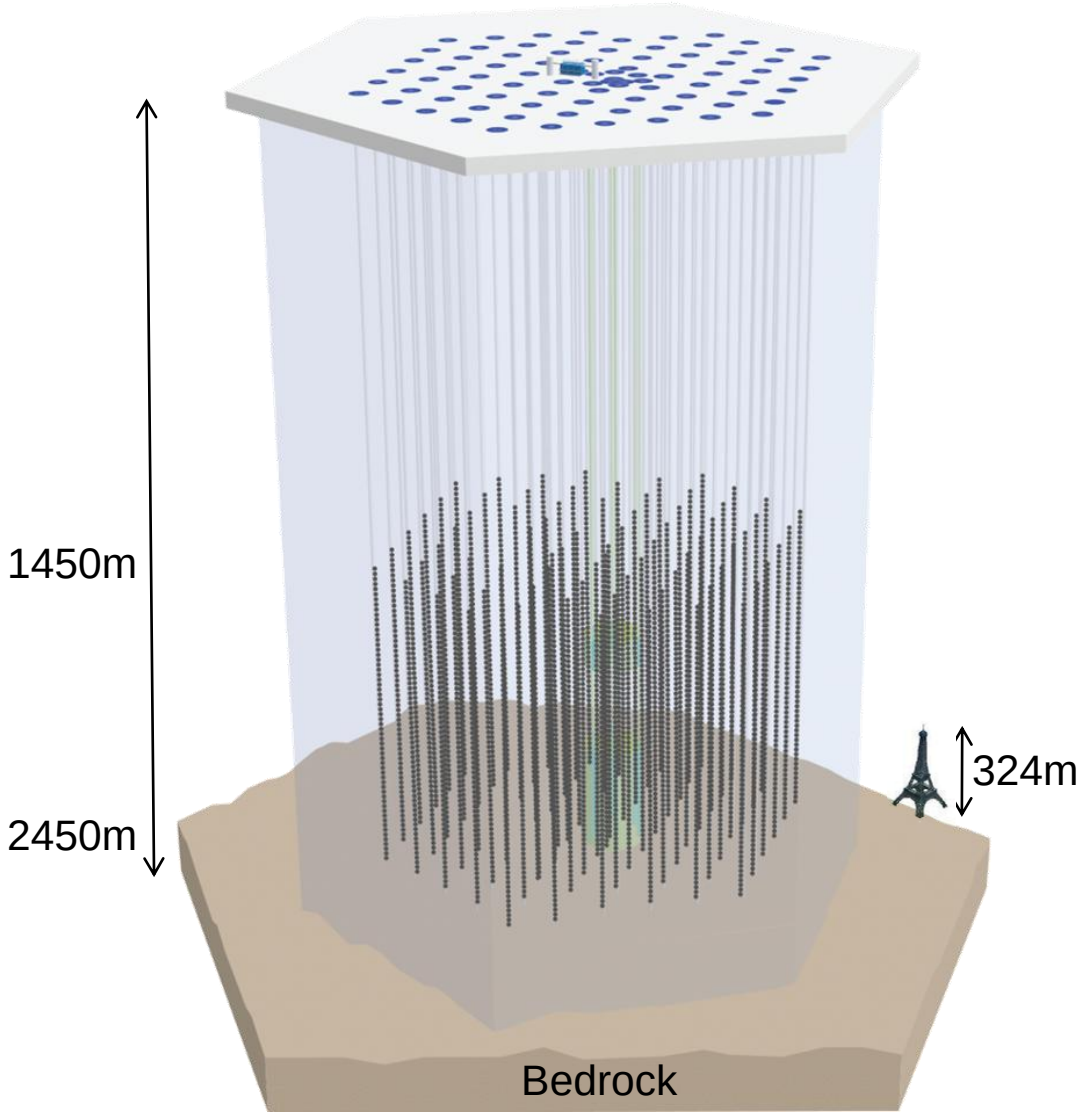
HELMHOLTZ

Picture credit: NSF/IceCube

What is IceCube?

Introduction to the IceCube Neutrino Observatory

- Detector volume: ~1km^3 of South Pole ice
- Detects neutrinos with energies from GeV to PeV
- Fully in operation since 2010



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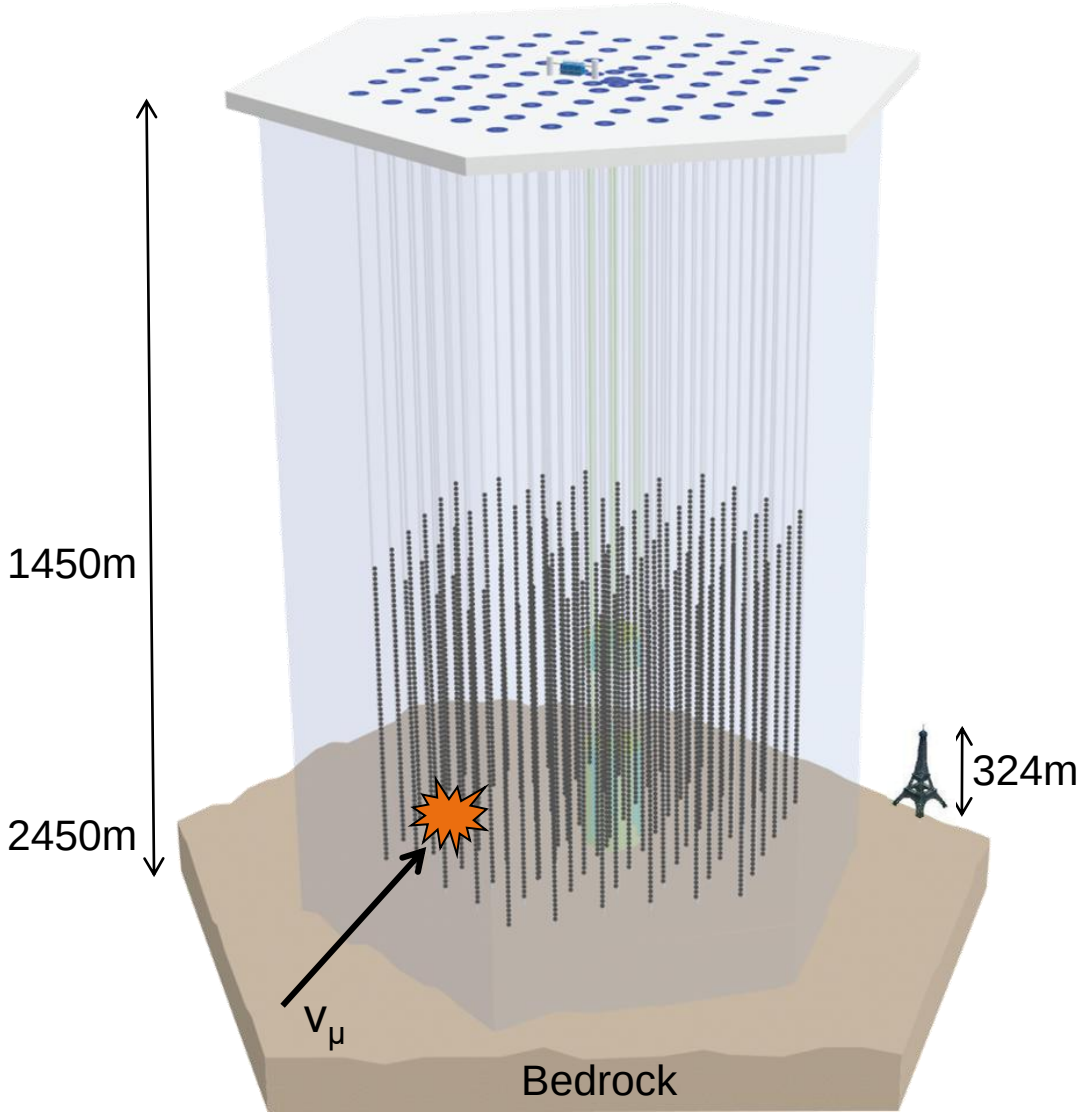

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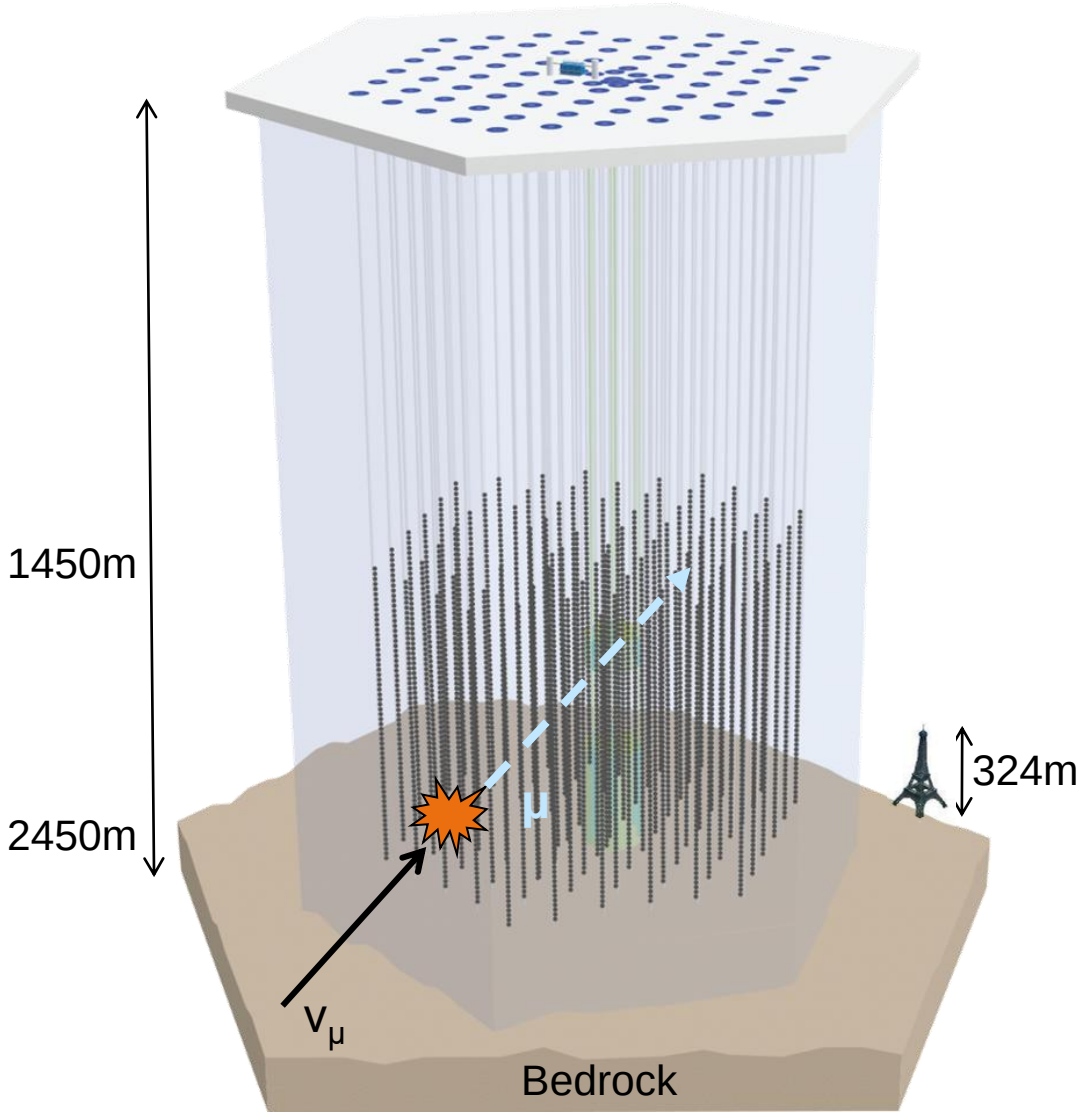

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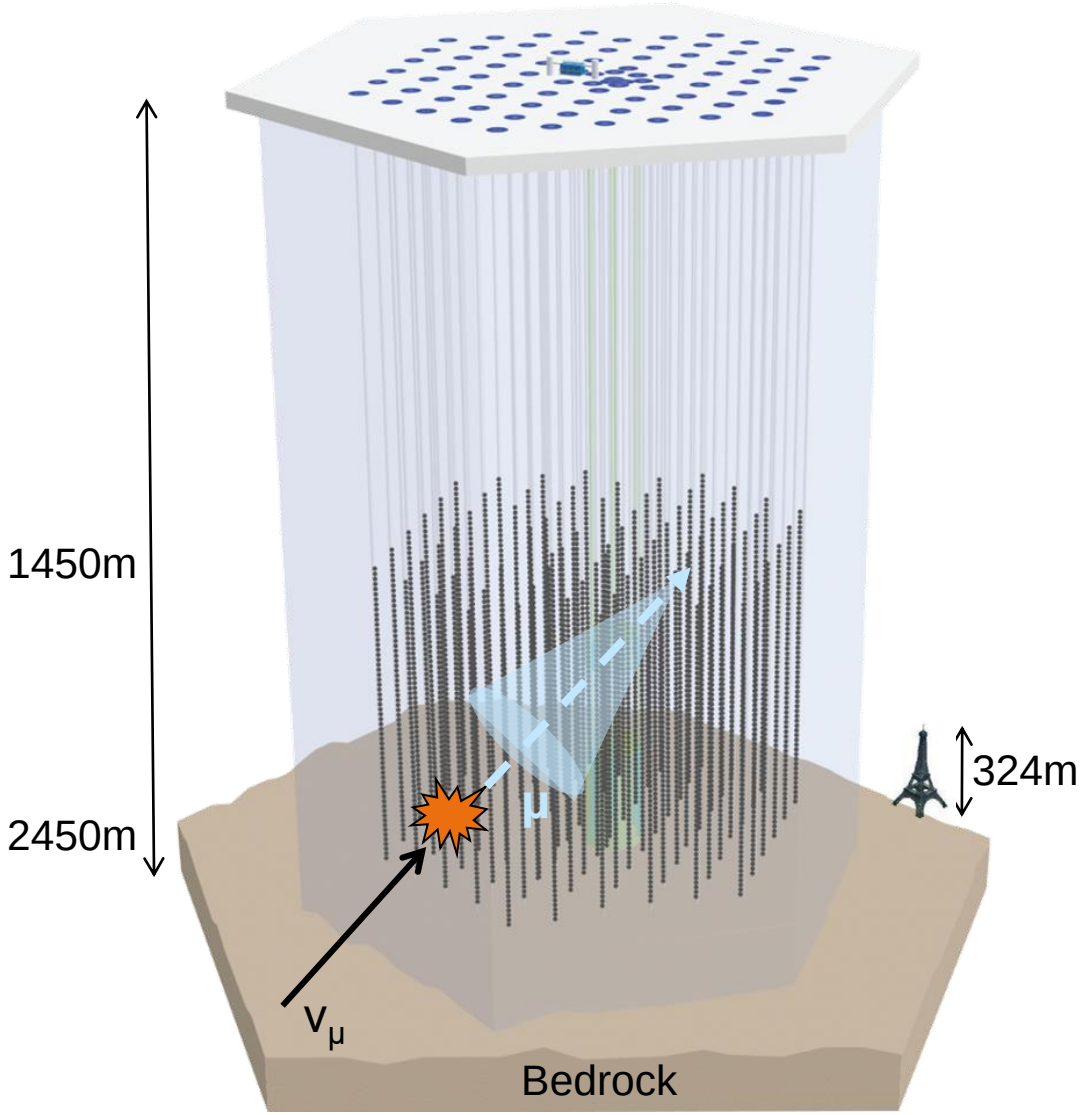

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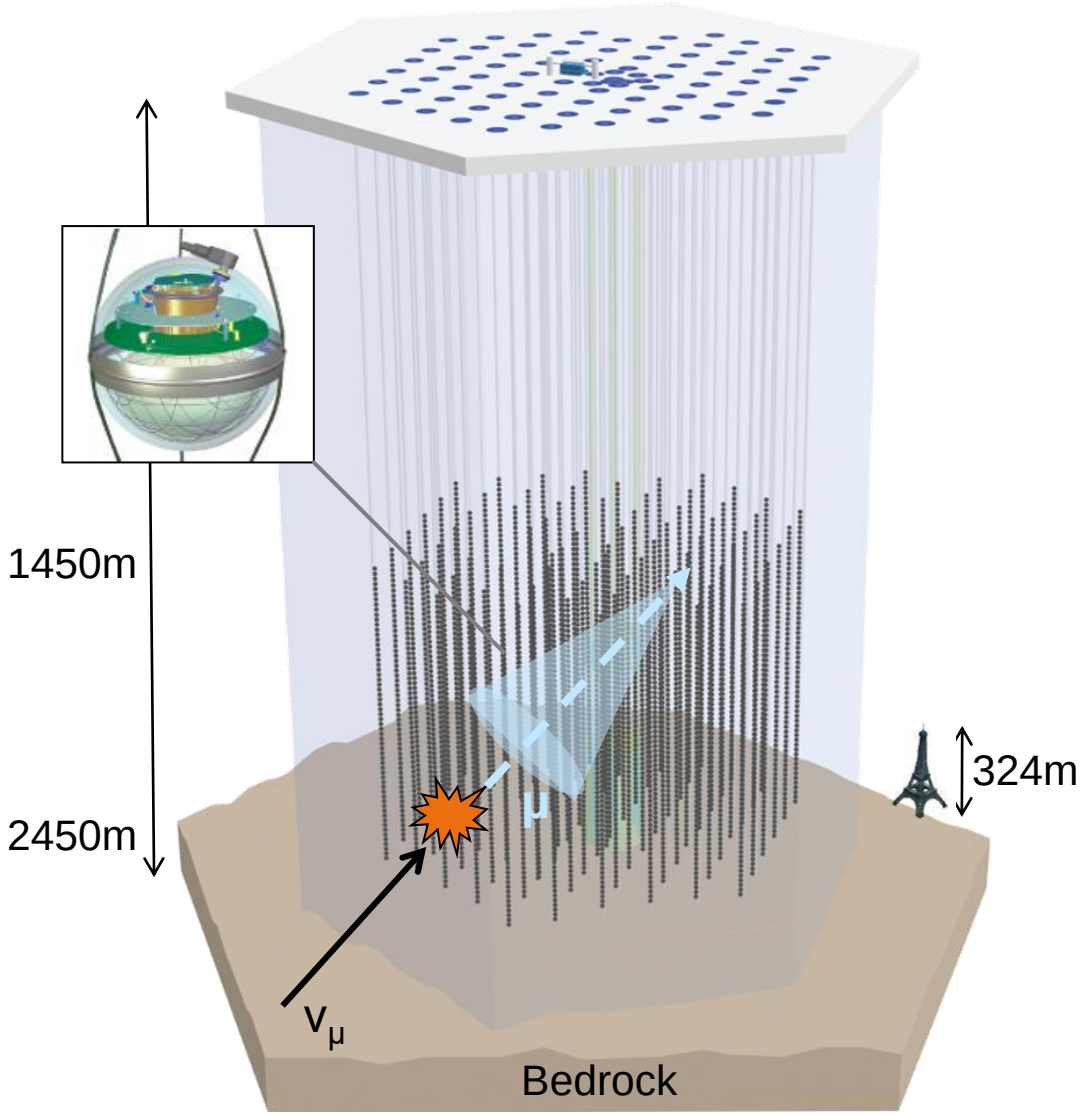
→ PMTs of 5160 Digital Optical Modules (DOMs) detect the photons



What is IceCube doing?

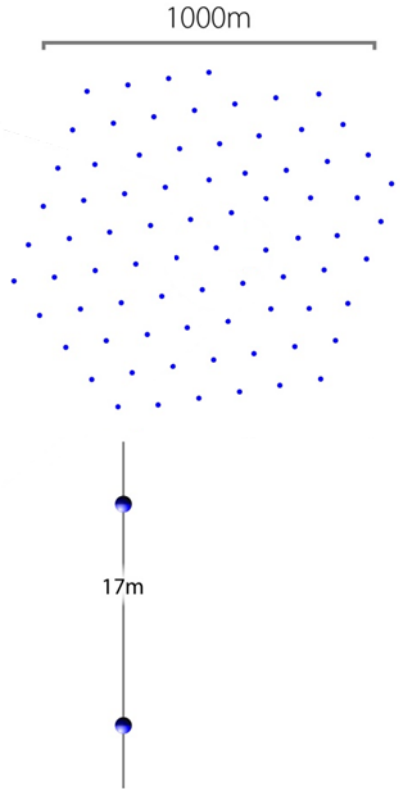
Research areas and some result highlights

- **Neutrino and multimessenger astronomy**:
  - astrophysical diffuse neutrino flux
  - astrophysical neutrino sources
  - galactic plane…
- **Neutrino physics**:
  - atmospheric neutrinos oscillations
  - sterile neutrino searches
  - nonstandard neutrino interactions…
- **Also**: cosmic ray physics, dark matter searches, neutrino Earth tomography, glaciology…

What is the IceCube Upgrade?

Low-energy extension to be installed in 2026

- **IceCube**: ~100 GeV energy threshold



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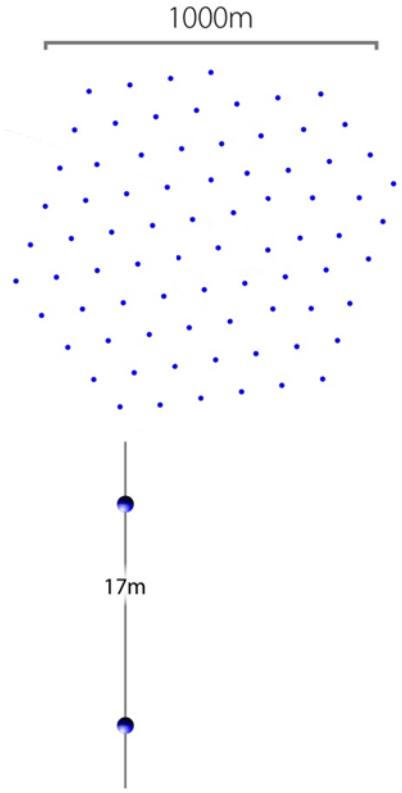
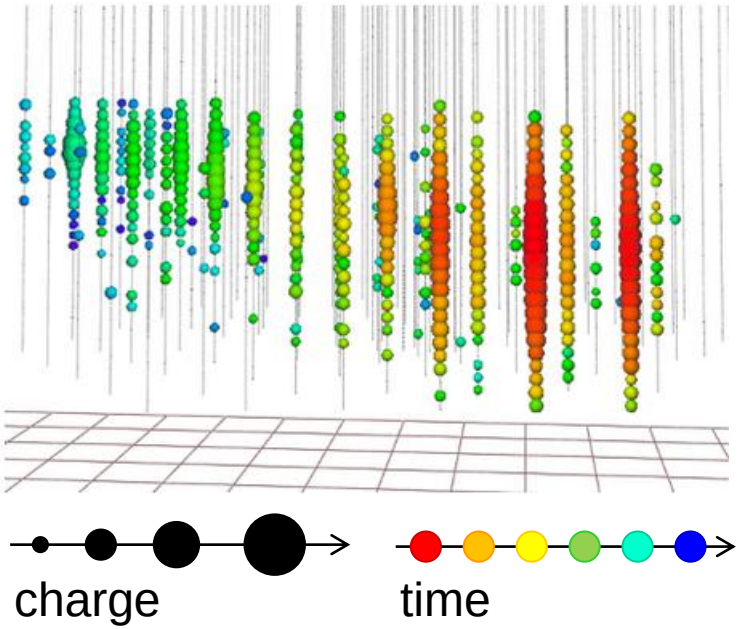


High-energy event (290 TeV)



What is the IceCube Upgrade?

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- **DeepCore**: densely spaced subdetector → lower energy threshold (~10 GeV)

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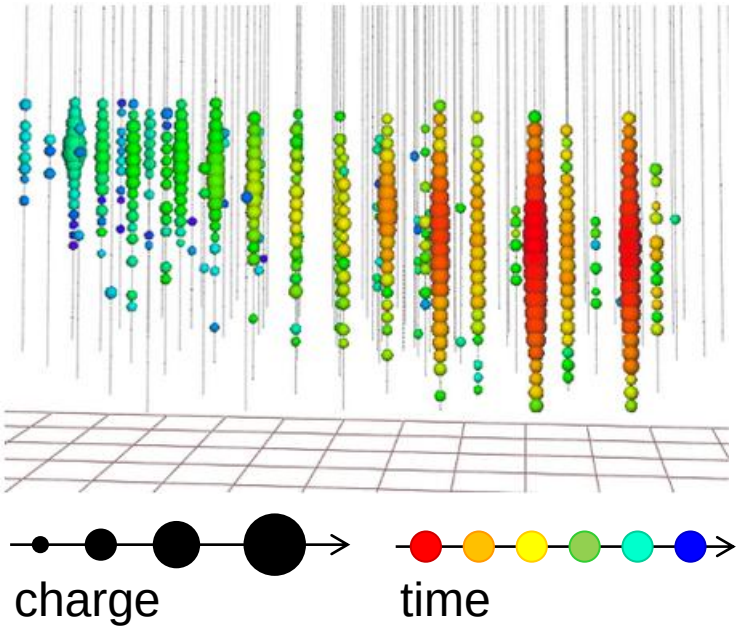

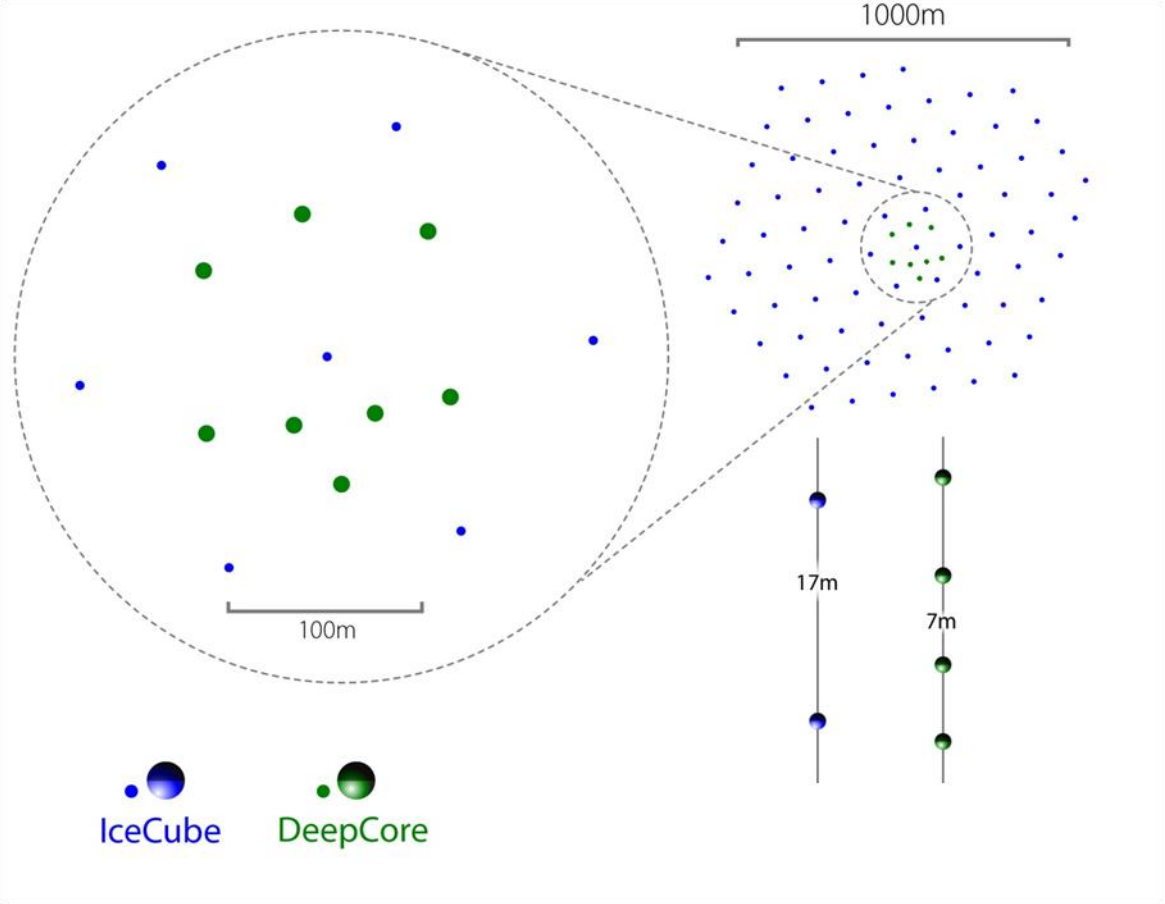

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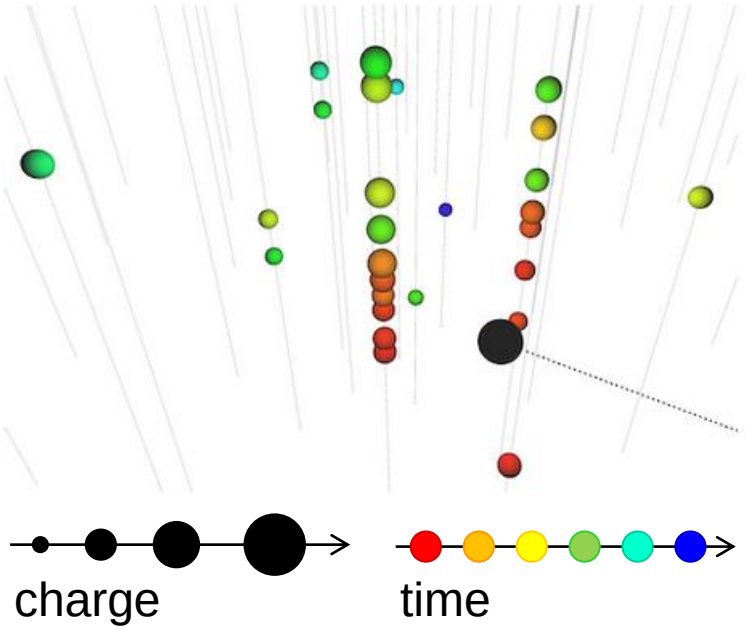
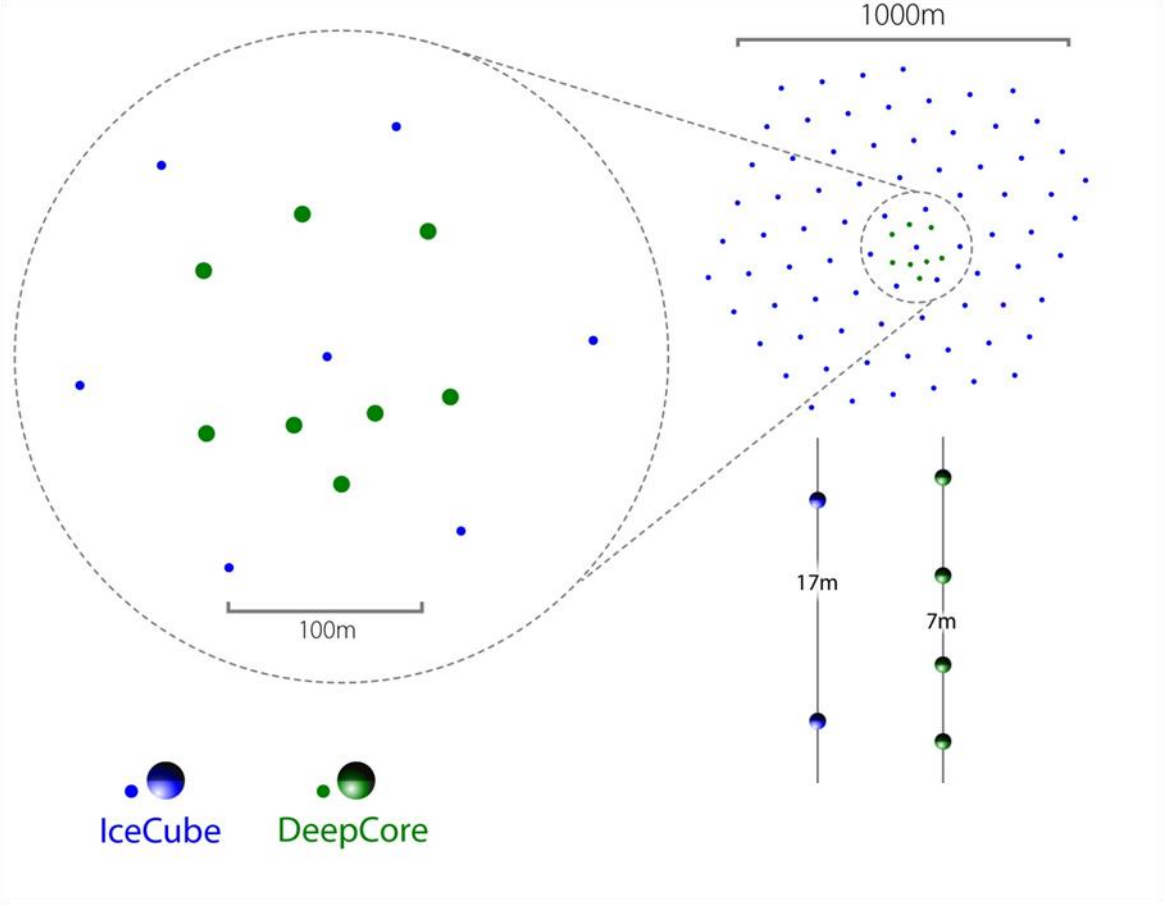
Low-energy event (25 GeV)





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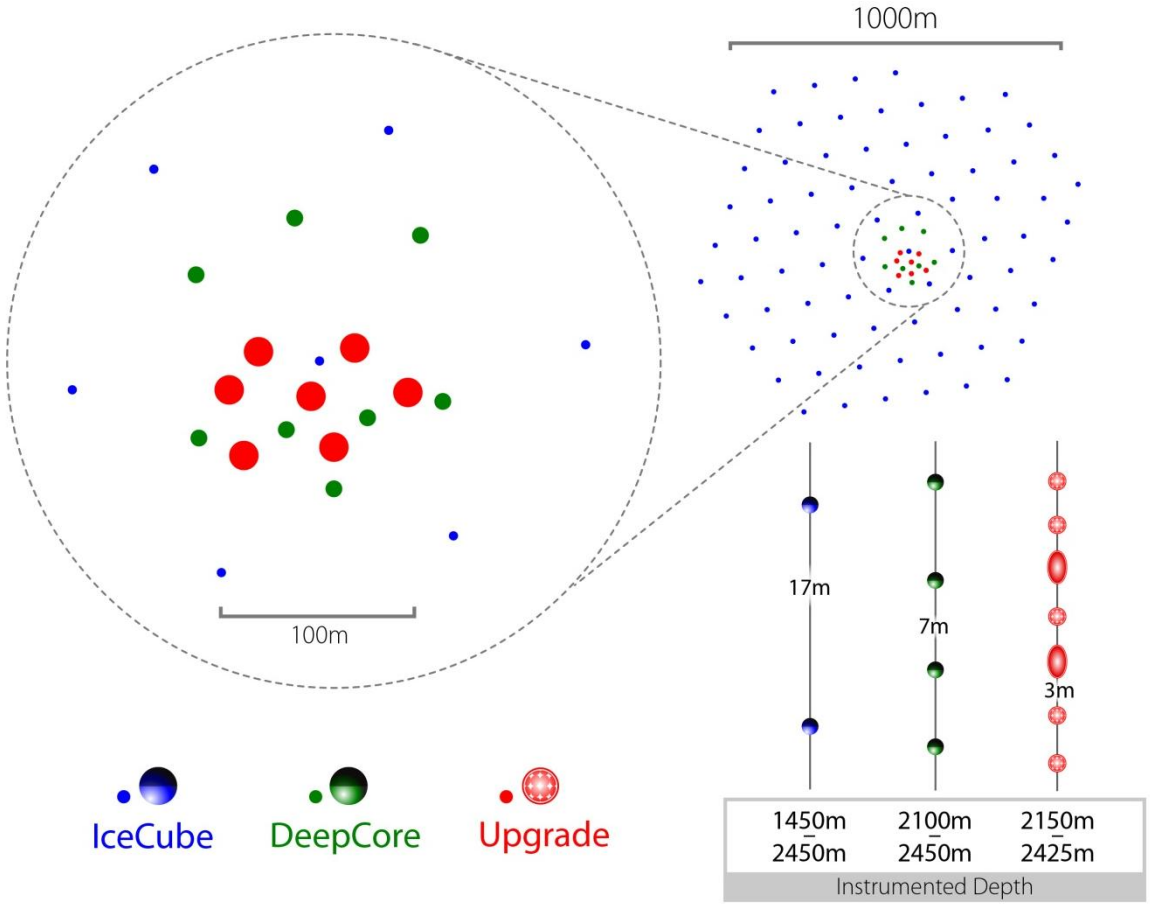
Low-energy extension to be installed in 2026

- **IceCube**: ~100 GeV energy threshold
- **DeepCore**: densely spaced subdetector → lower energy threshold (~10 GeV)
- **Upgrade**: reduce energy threshold to a few GeV

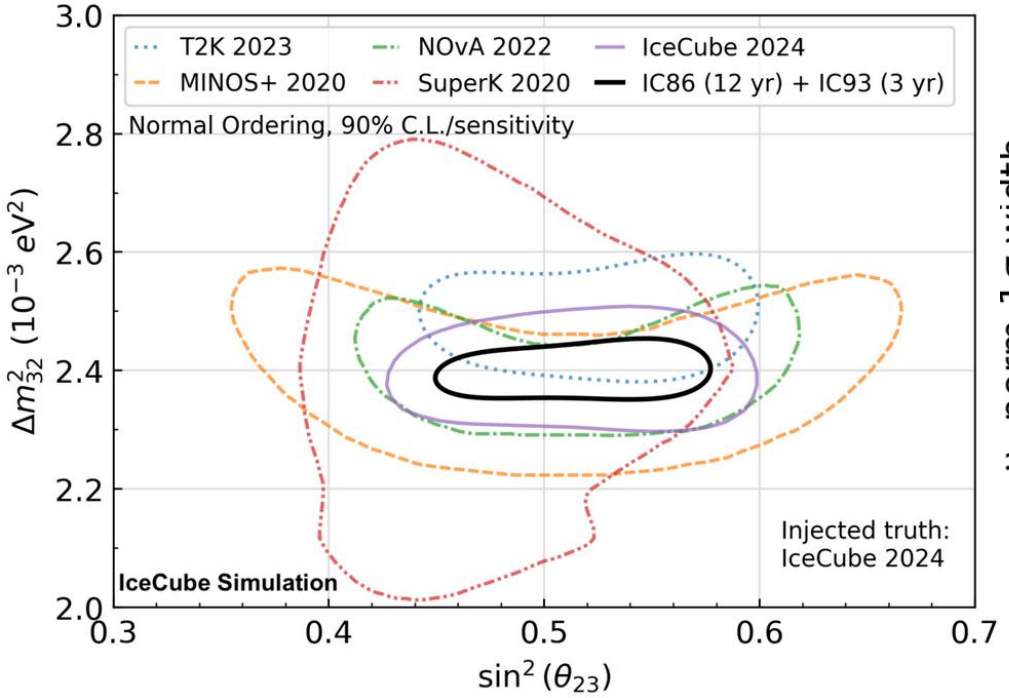


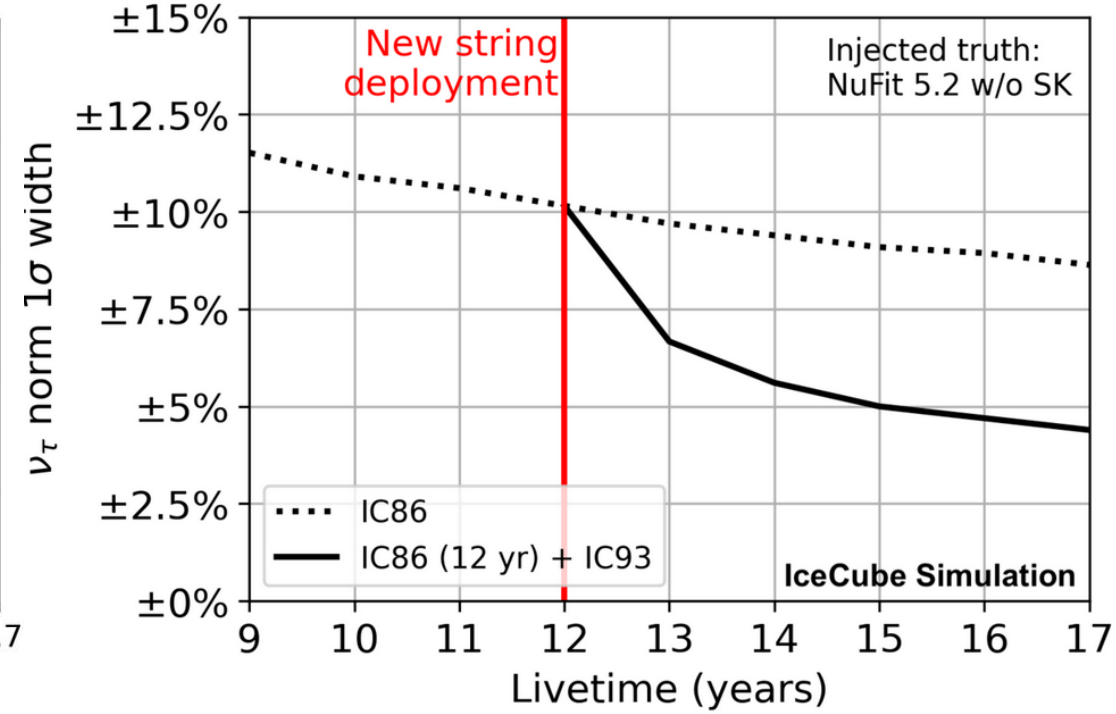
Why does IceCube need an Upgrade?

Goals of the IceCube Upgrade

Improvements in:

- Detection efficiency (GeV scale)
- Energy and zenith reconstruction
- **Neutrino oscillation parameters determination**
- **ν_τ appearance measurements**
- Probing neutrino mass ordering
- Detector calibration





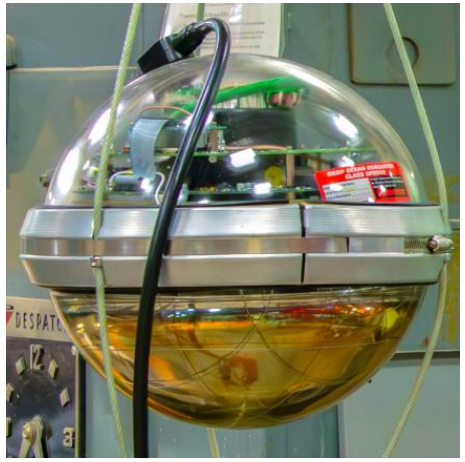
The IceCube Upgrade also allows to test different optical module designs for IceCube-Gen2

How to achieve these goals

A new generation of optical modules

New detector modules:

- **D-Egg** (**D**ual optical sensors in an **E**llipsoid **G**lass for **G**en2)
- **mDOM** (**m**ulti-PMT **D**igital **O**ptical **M**odule)
- About 700 new optical modules with multiple PMTs and…



IceCube DOM (1x10'' PMT)

IceCube Upgrade D-Egg (2x8'' PMTs)

IceCube Upgrade mDOM (24x3'' PMTs)

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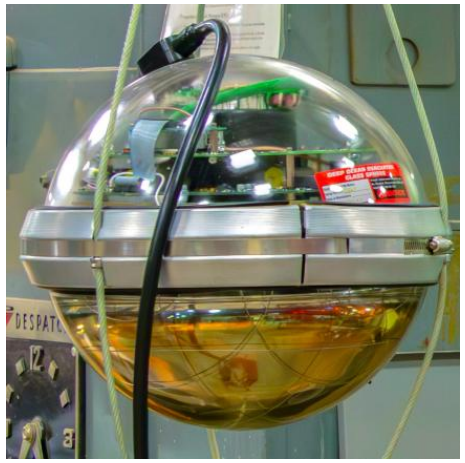
- Calibration devices: LEDs and cameras



IceCube DOM (1x10'' PMT)

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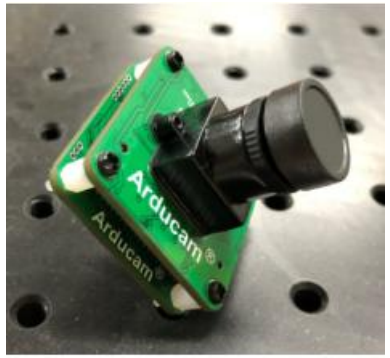
IceCube Upgrade mDOM (24x3'' PMTs)



Camera design and testing: SKKU (Korea) and University of Utah (USA)

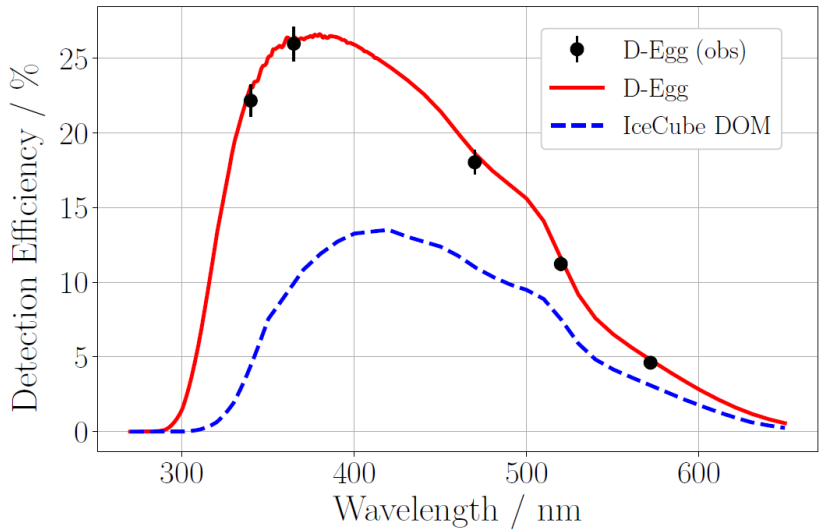
The D-Egg

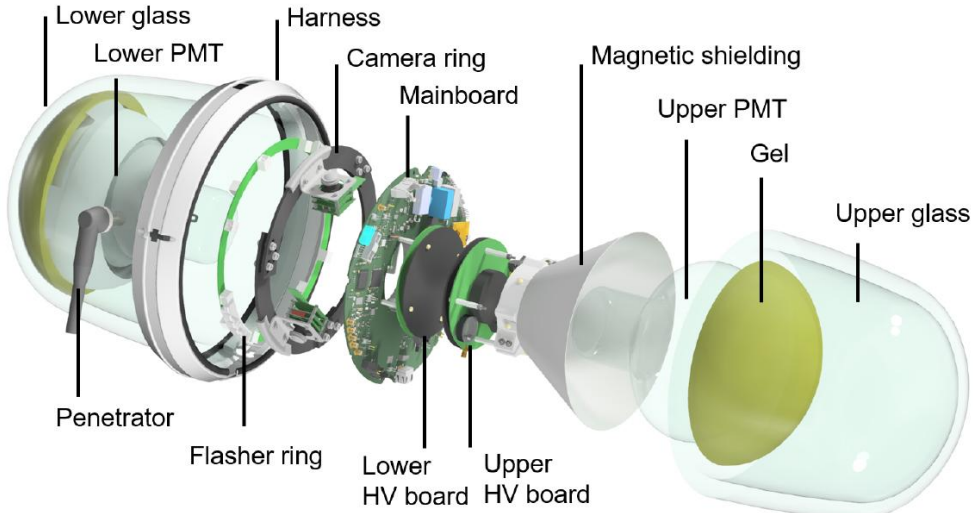
Into the details

- Deployment of ~280 D-Eggs in the IceCube Upgrade
- One integration and testing facility: Chiba University (Japan)

Advantages:

- UV transparent glass and gel → photon efficiency
- Narrow diameter (30cm) → lower drilling costs





D-Egg Paper (2023)

The mDOM

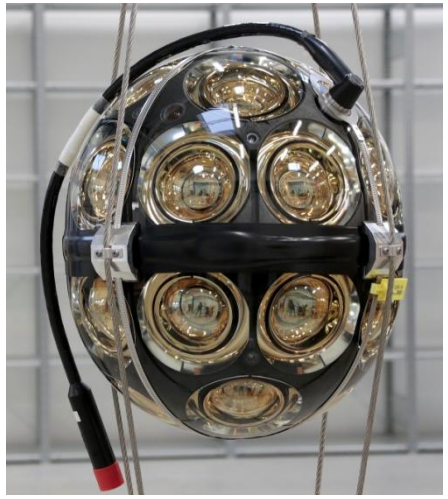
Into the details

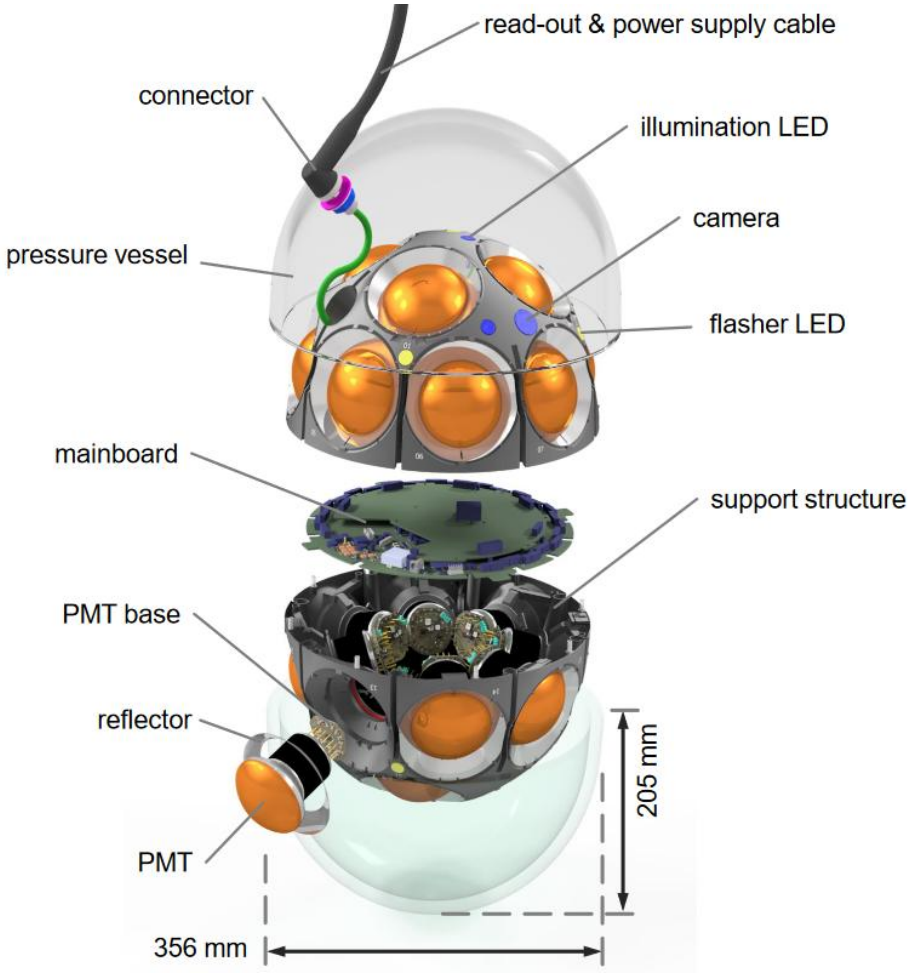
- Deployment of ~400 mDOMs in the IceCube Upgrade
- Two integration and testing facilities: DESY in Zeuthen (Germany), Michigan State University (USA)

Advantages:

- Local coincidence possible for background rejection
- Almost uniform angular acceptance

ICRC Proceedings (2023)
PMT Testing Paper (2024)





mDOM Production and Testing

At DESY Zeuthen (Germany)

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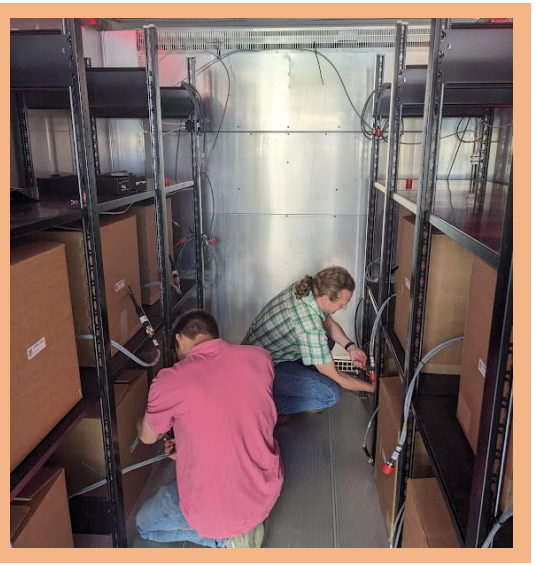

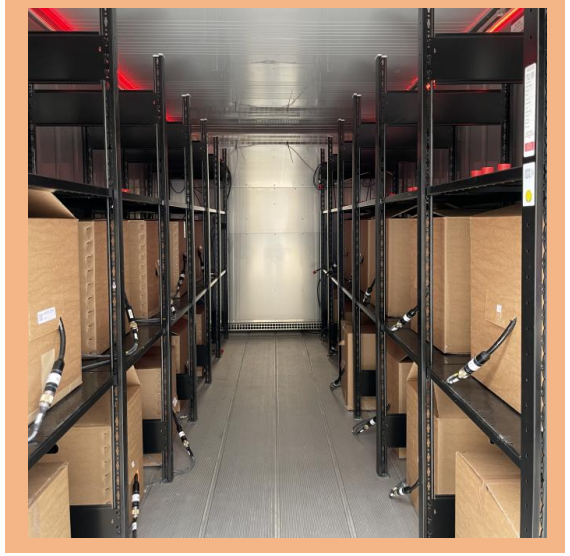

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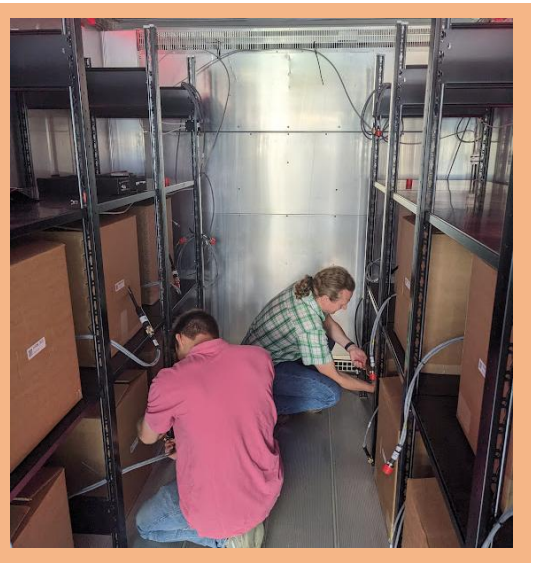

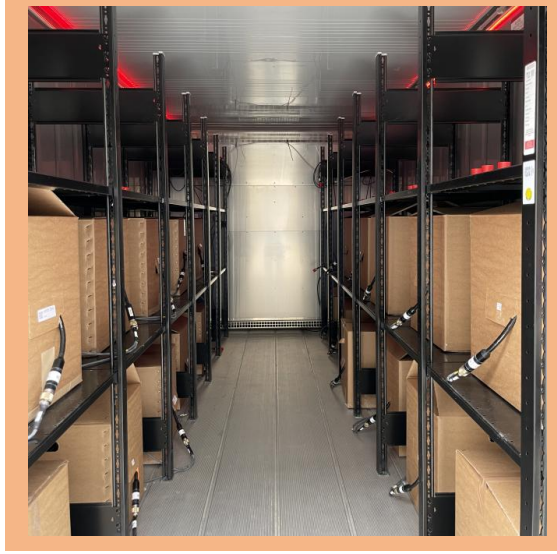

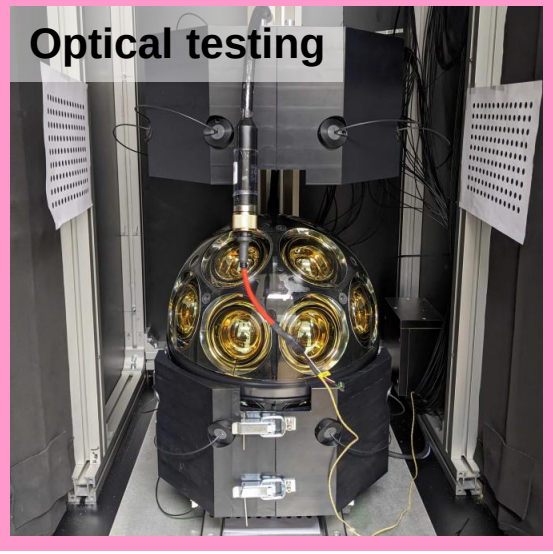

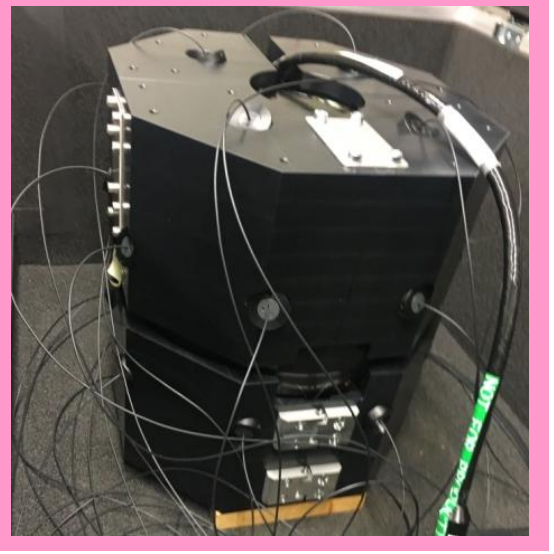

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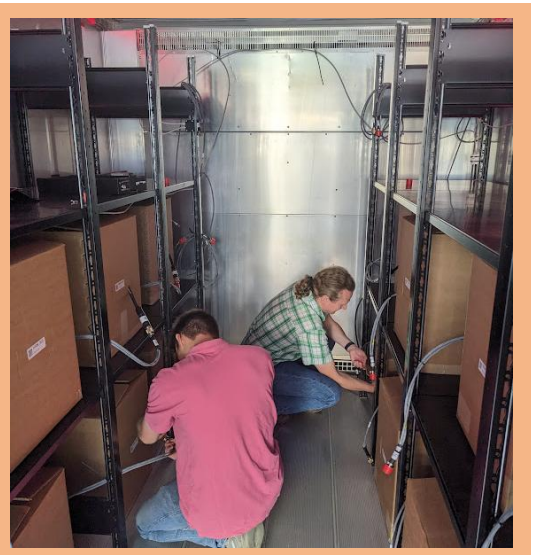
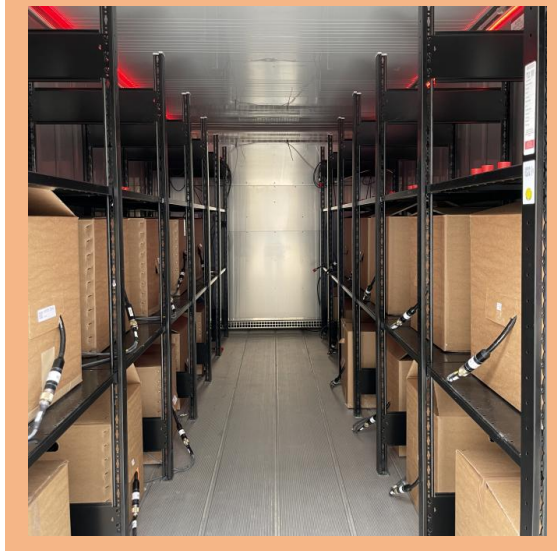
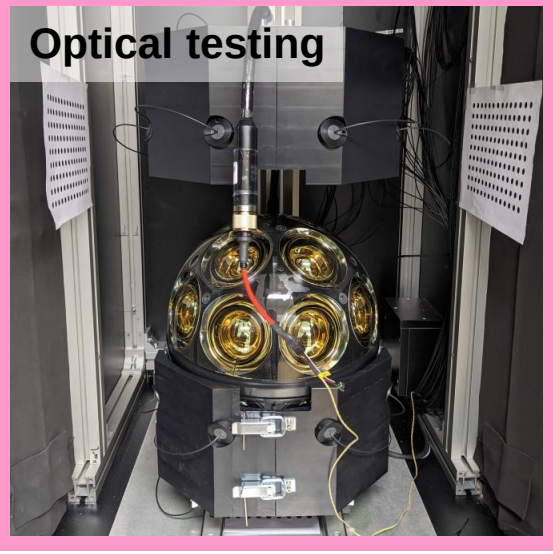
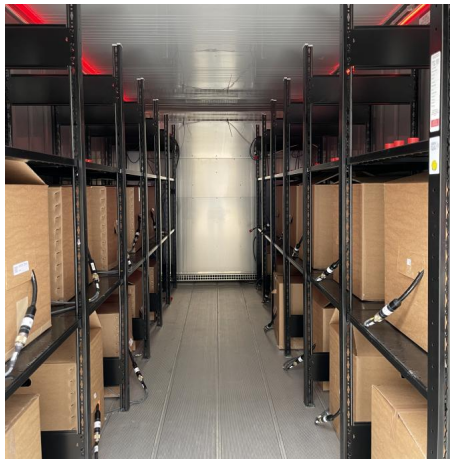






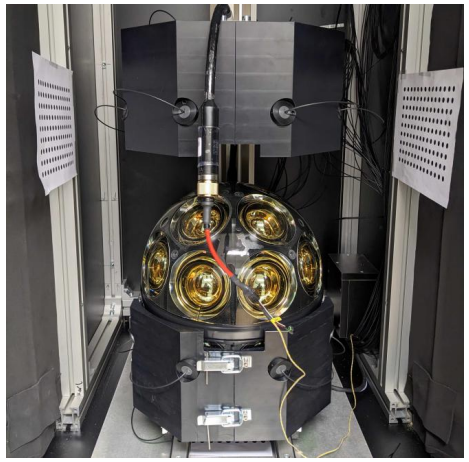
mDOM Testing

Before shipment



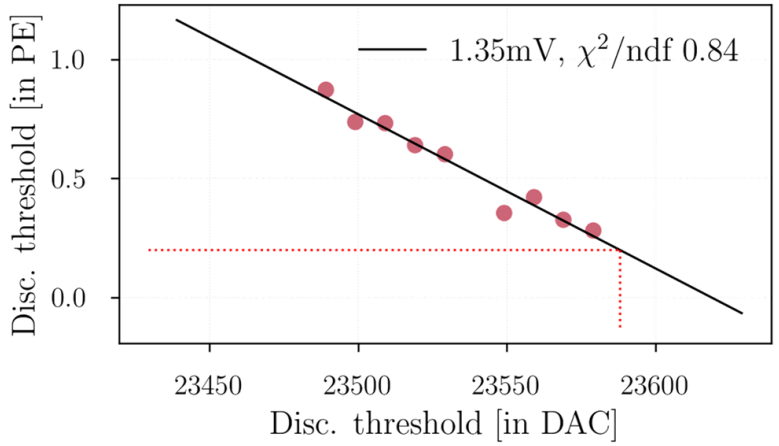
Dark and cold testing:

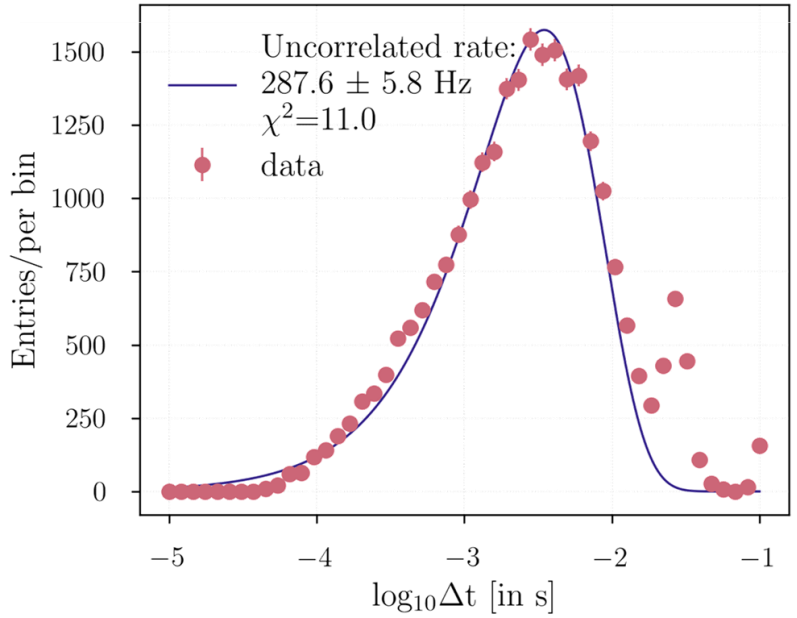
- **Channel calibration**
- **Dark rate**
- Camera & flasher tests



Opical testing:

- Linearity measurement
- Transit time measurement
- Camera tests
- PMT cabling check





Where are we now?

Timeline and status of production, testing and deployment

- All D-Eggs produced and tested
- mDOM: production and testing ongoing
- Planned number of modules for shipment 2024 ready
- Drilling started last season

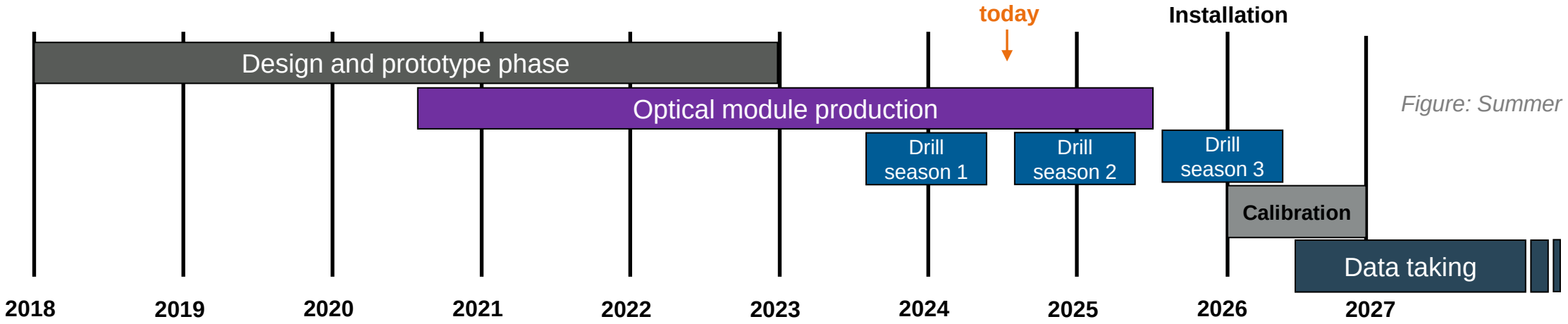
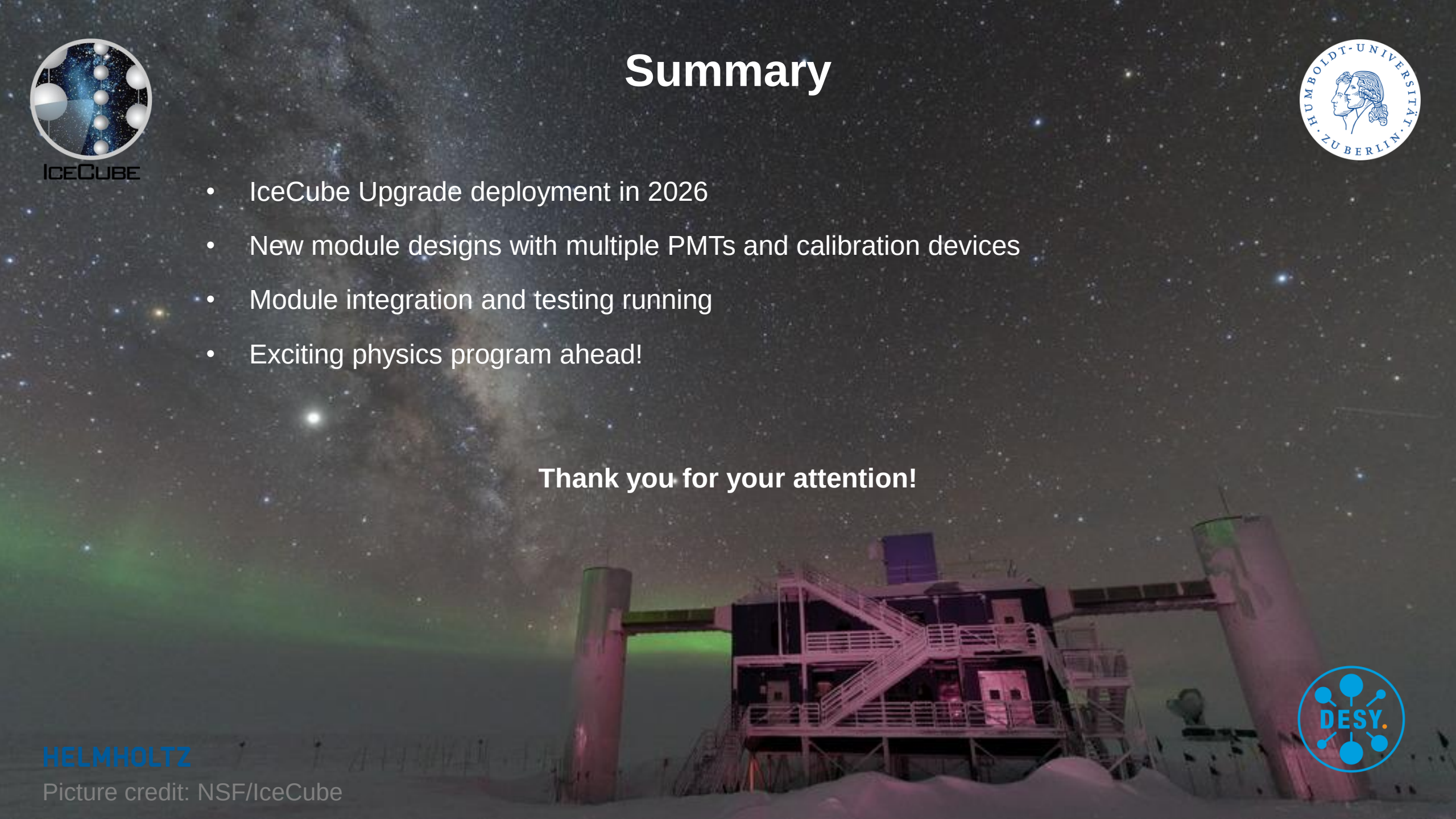


Figure: Summer Blot

Summary

- IceCube Upgrade deployment in 2026
- New module designs with multiple PMTs and calibration devices
- Module integration and testing running
- Exciting physics program ahead!

Thank you for your attention!



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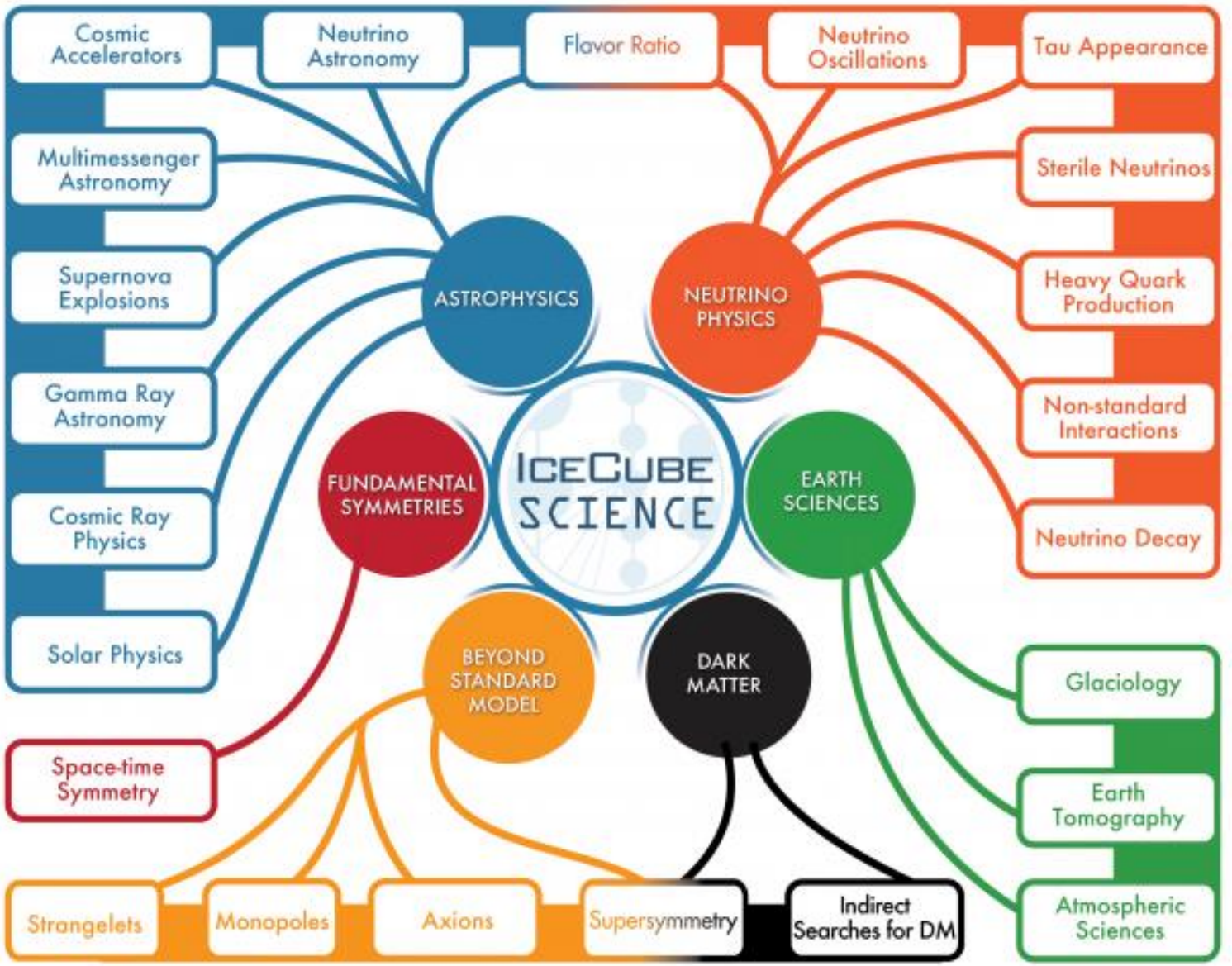
Picture credit: NSF/IceCube

Backup

IceCube Science



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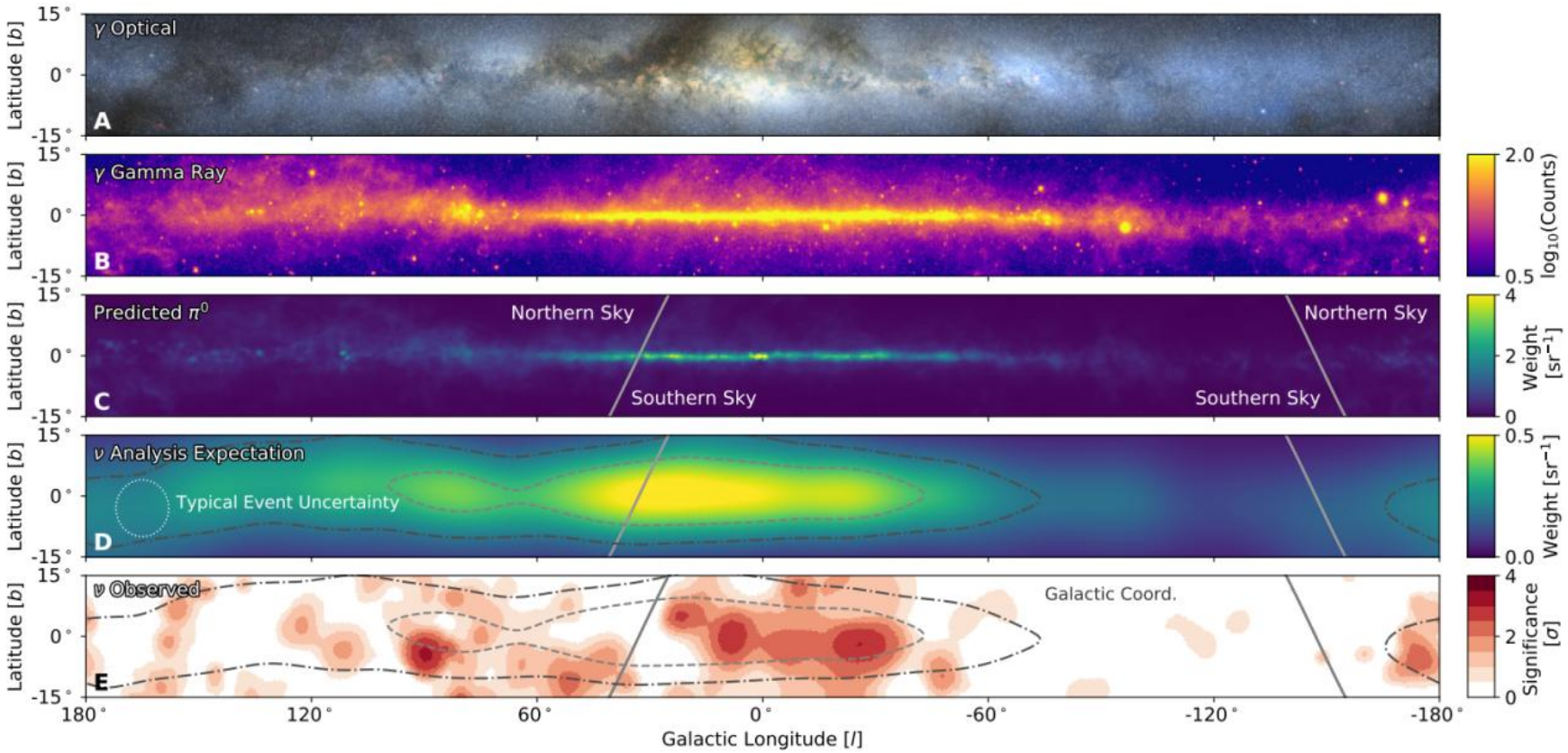
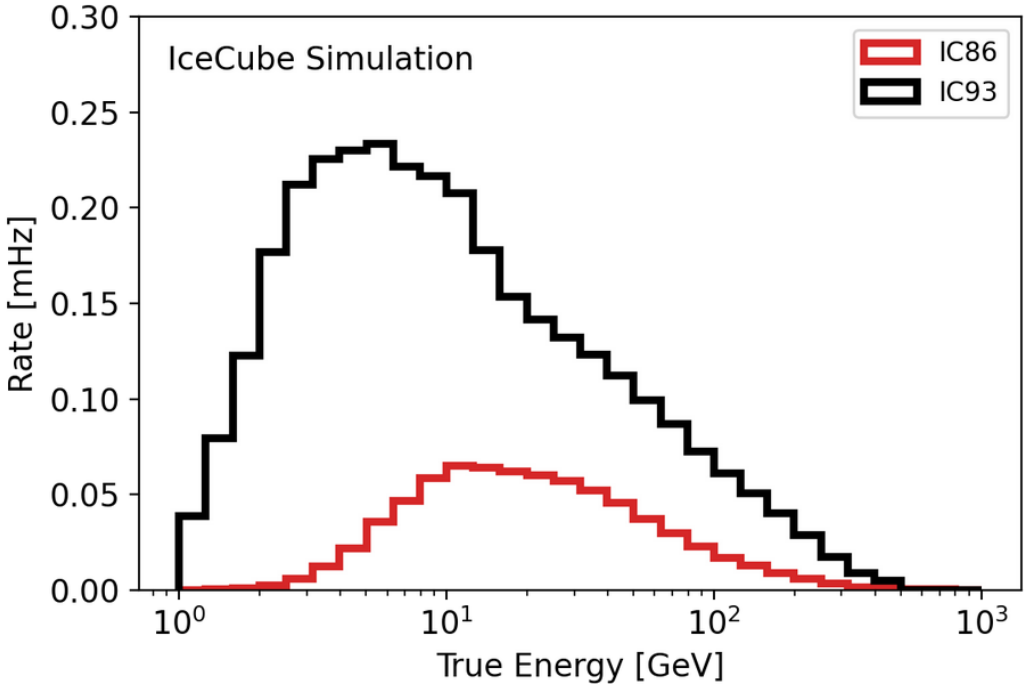
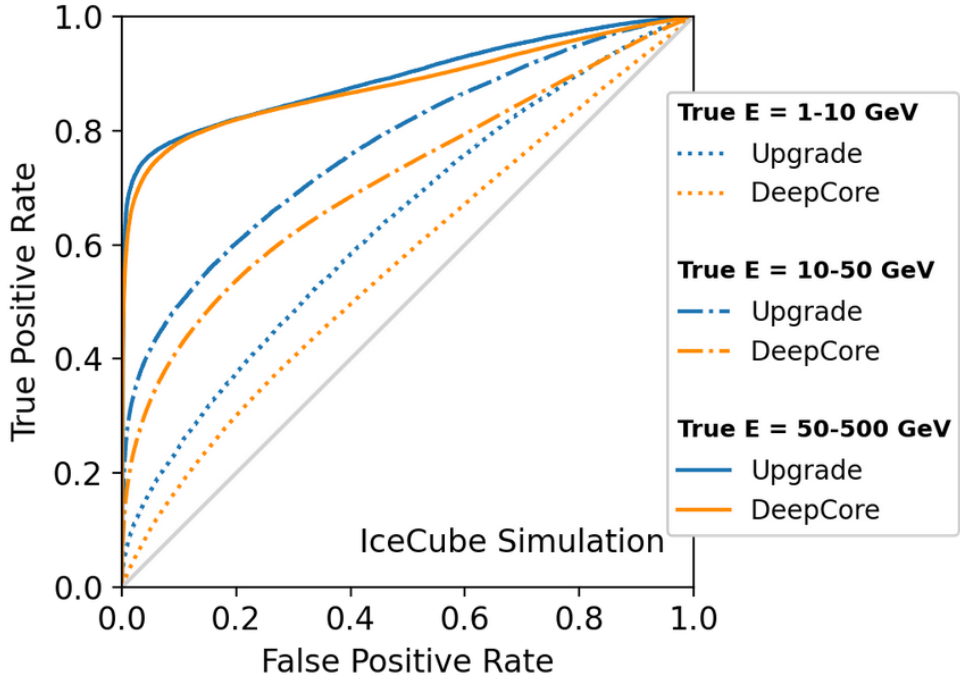


Why does IceCube need an Upgrade?

Goals of the IceCube Upgrade

Improvements in detection efficiency (GeV scale)





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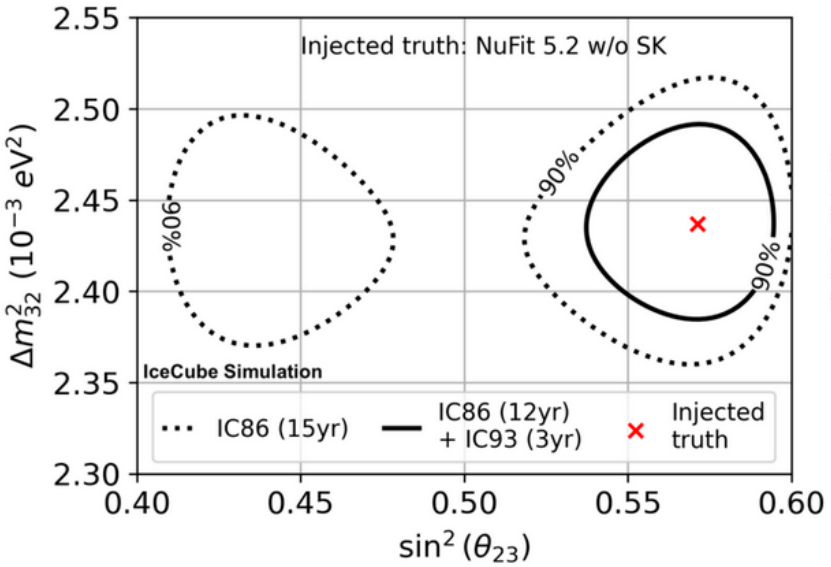
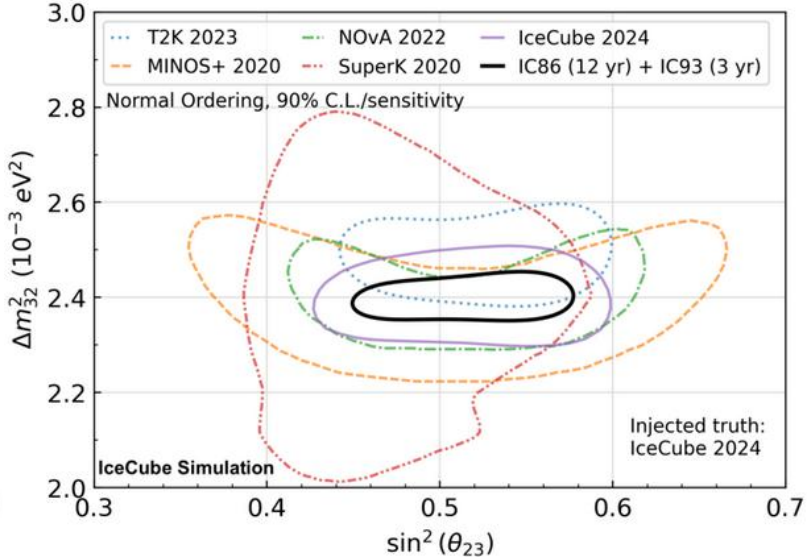
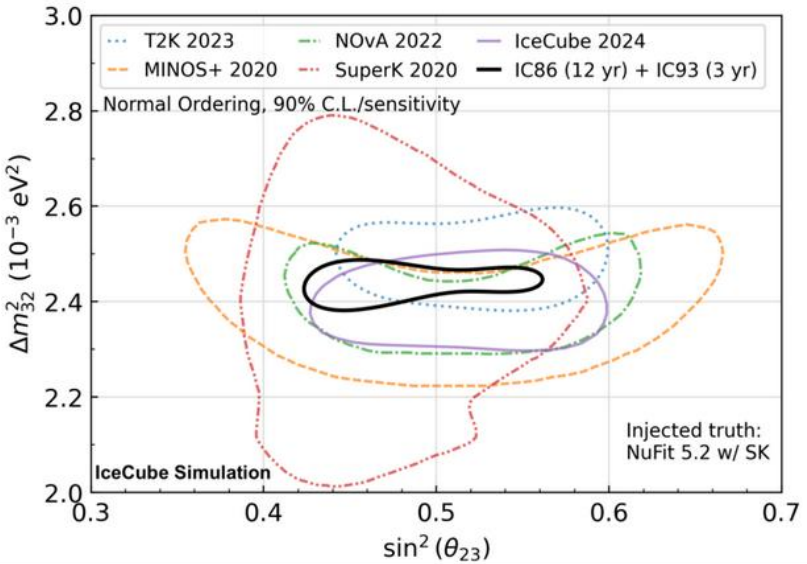
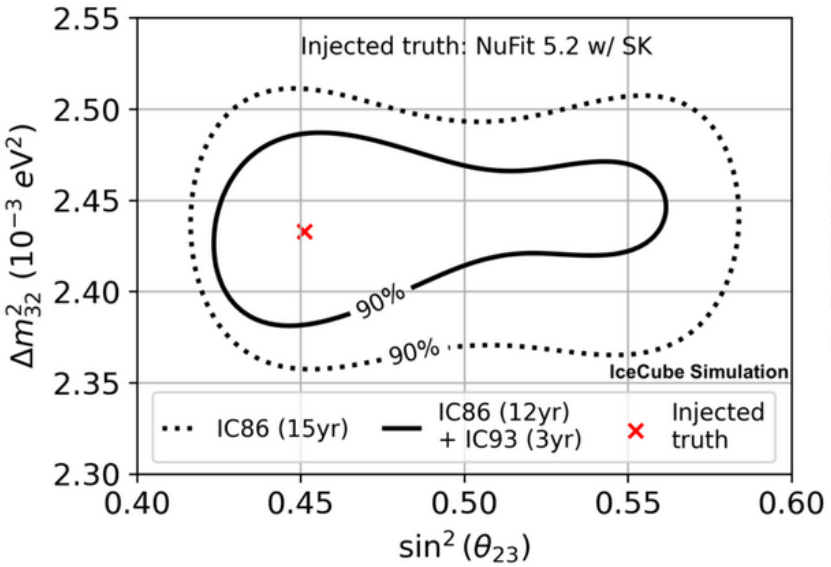
ν_μ Disappearance and ν_τ Appearance

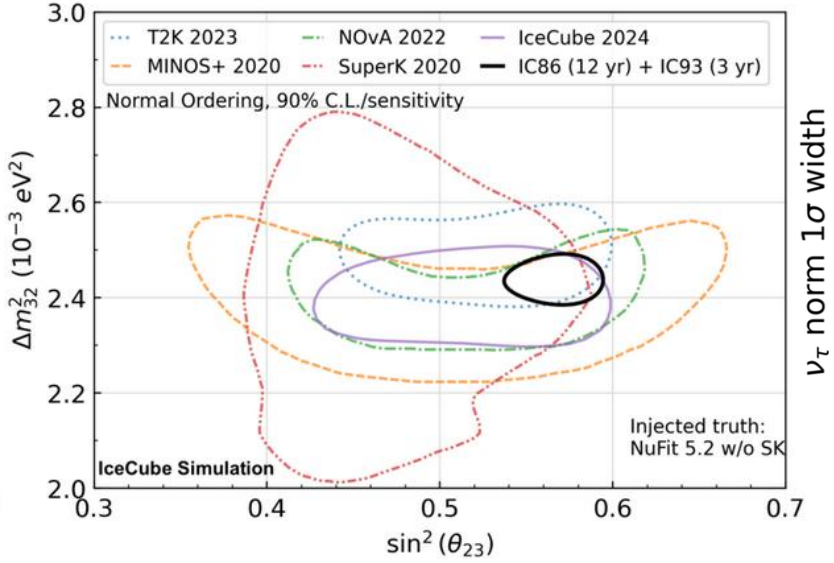
Atmospheric neutrino oscillations

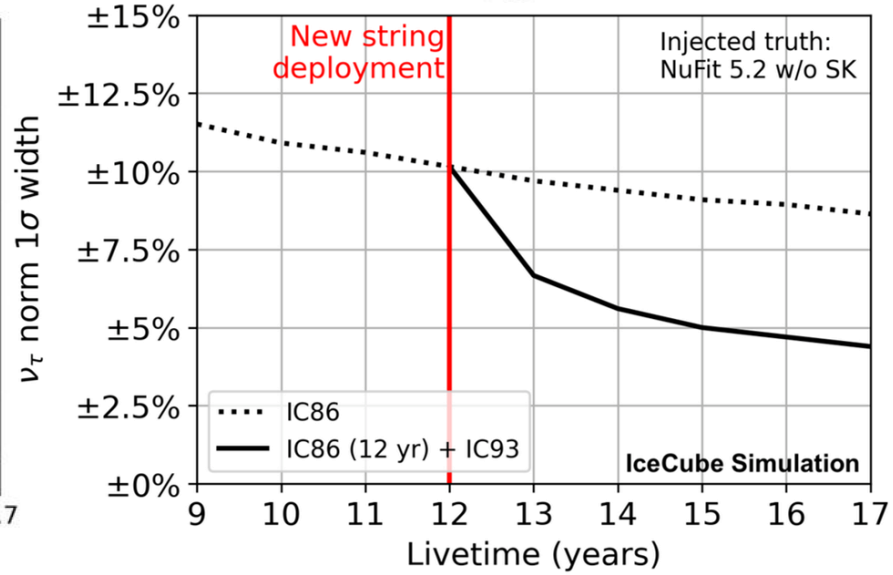






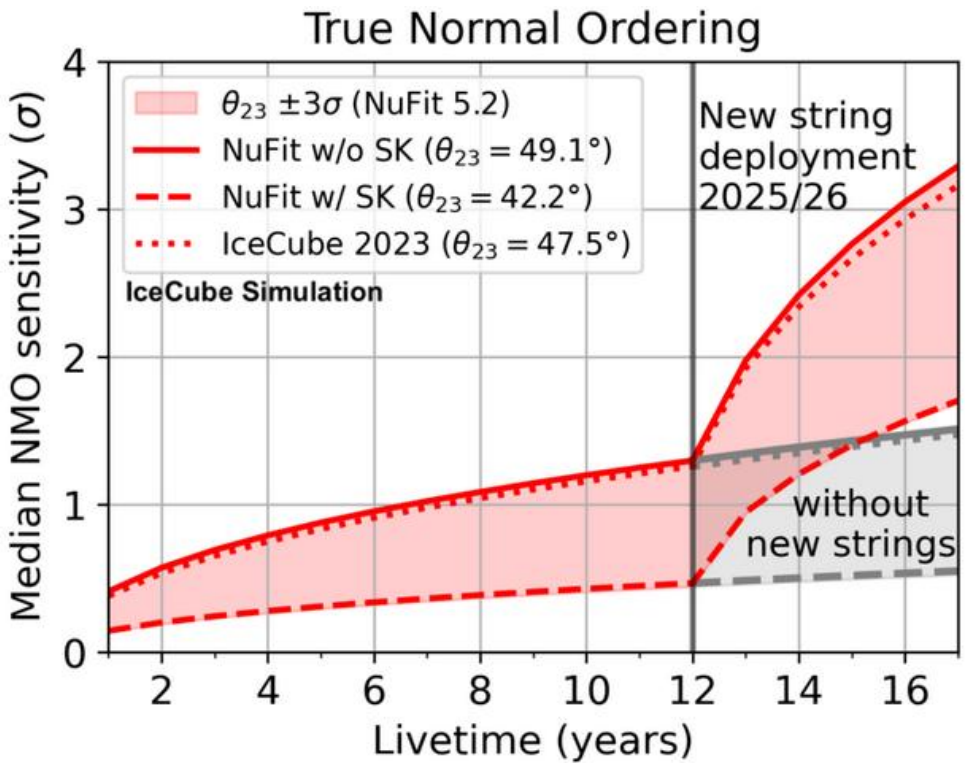


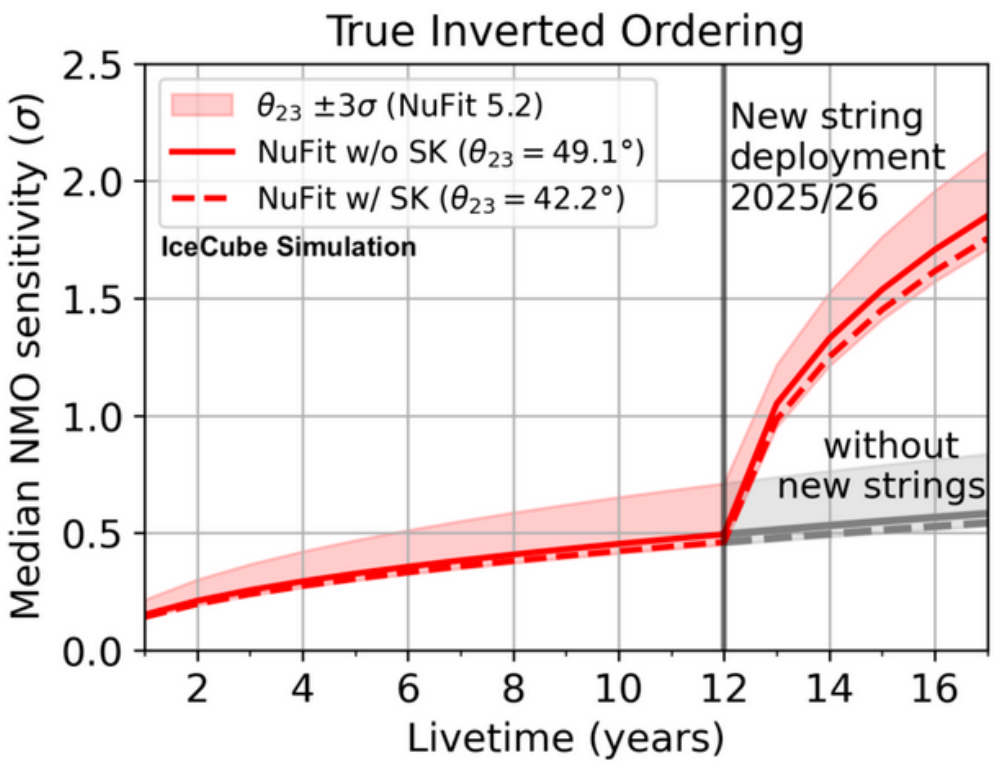




Neutrino Mass Ordering

Normal ordering and inverted ordering





mDOM Testing

Results presented at ICRC 2023