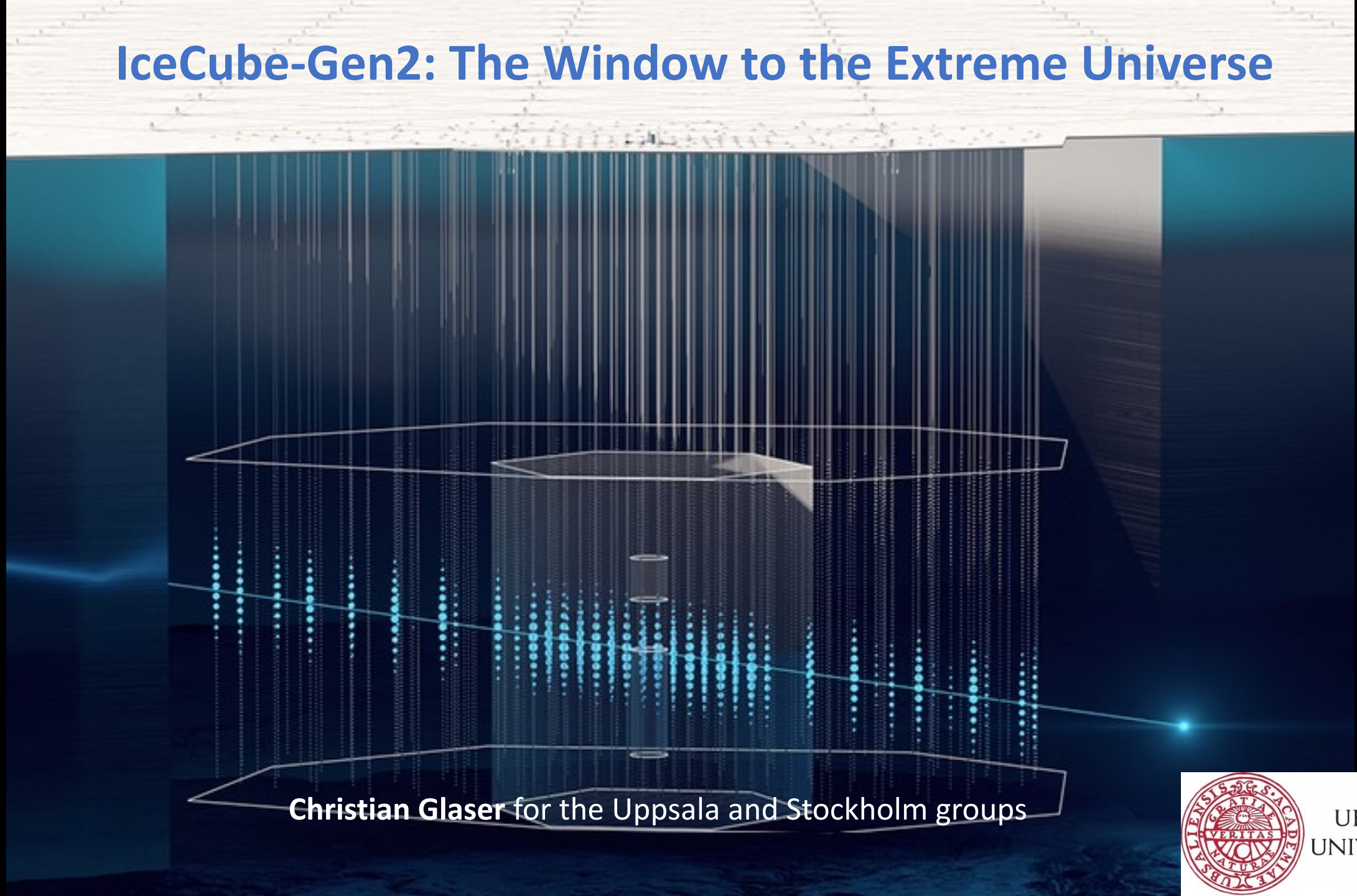
IceCube-Gen2: The Window to the Extreme Universe



Christian Glaser for the Uppsala and Stockholm groups

UPPSALA UNIVERSITET

IceCube

Many first discoveries

but

- limited statistics
- limited angular resolution
- limited energy reach (only up to 10 PeV, not yet at the most powerful sources)

IceCube-Gen2

Neutrino Astronomy

what do we need?

more neutrinos, with better quality

better optical detector

- ~10x larger volume -> 10x larger event rate
- better event quality (angular resolution)

larger energy reach

(to EeV energies)

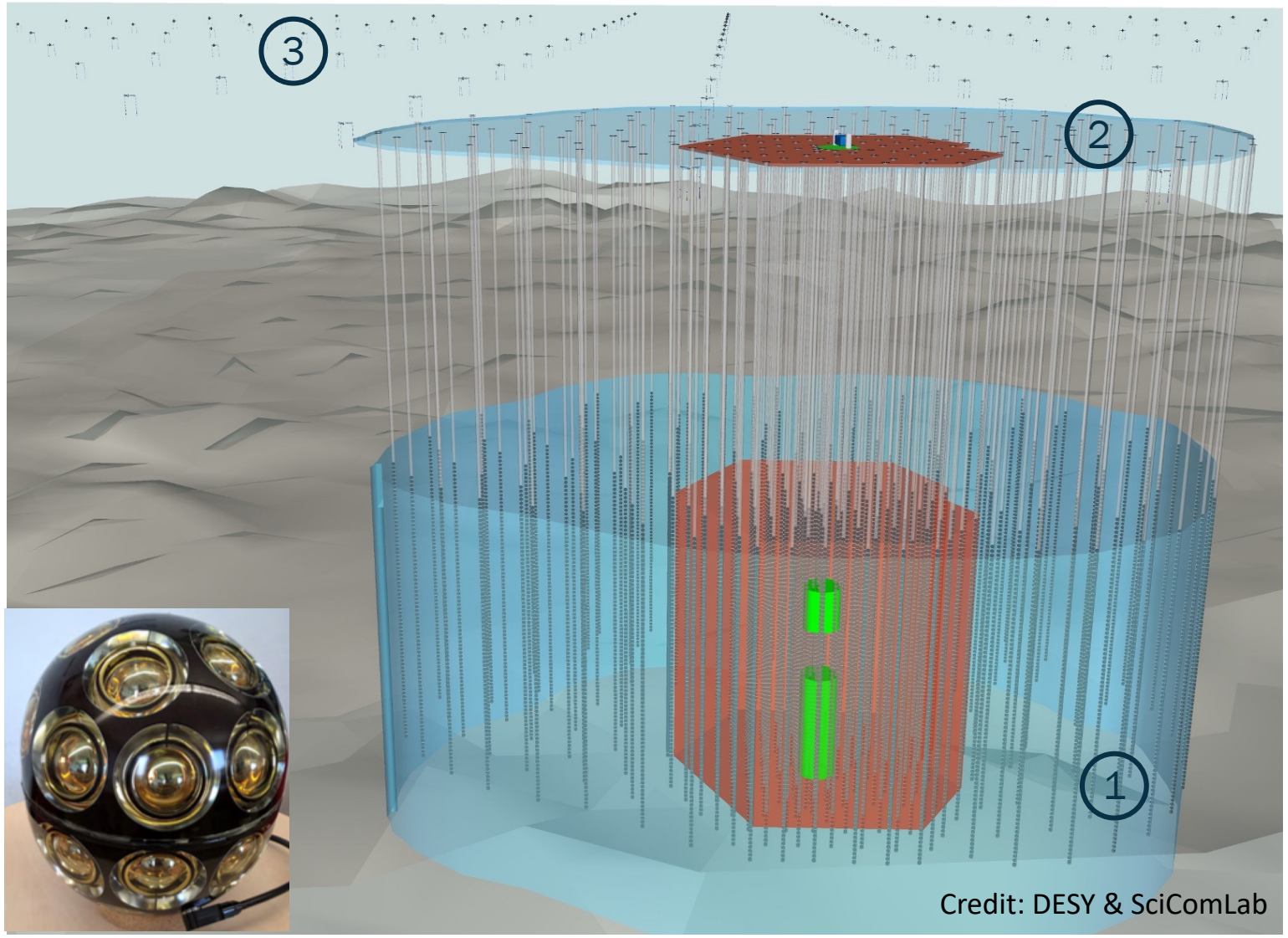
radio detector

- cost efficient instrumentation of huge volumes

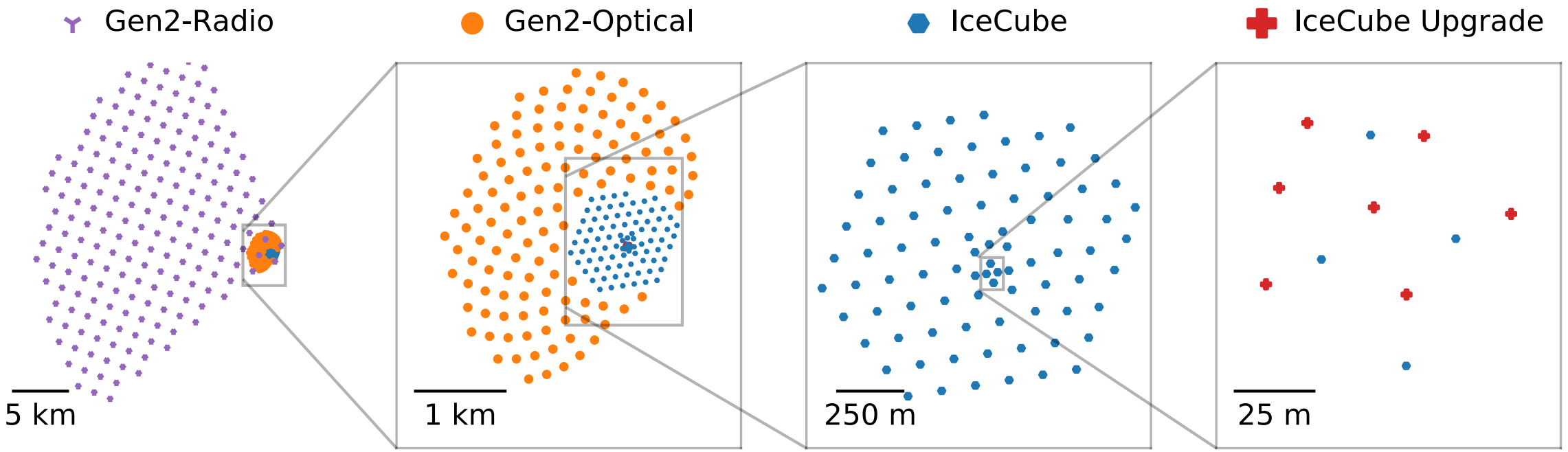
IceCube-Gen2

Four new elements, leveraging complementary technologies, to achieve sensitivity to MeV-EeV neutrinos

1. **Enlarged deep optical array**
2. Surface Array
3. **Shallow radio array**
   - expands energy reach to EeV energies



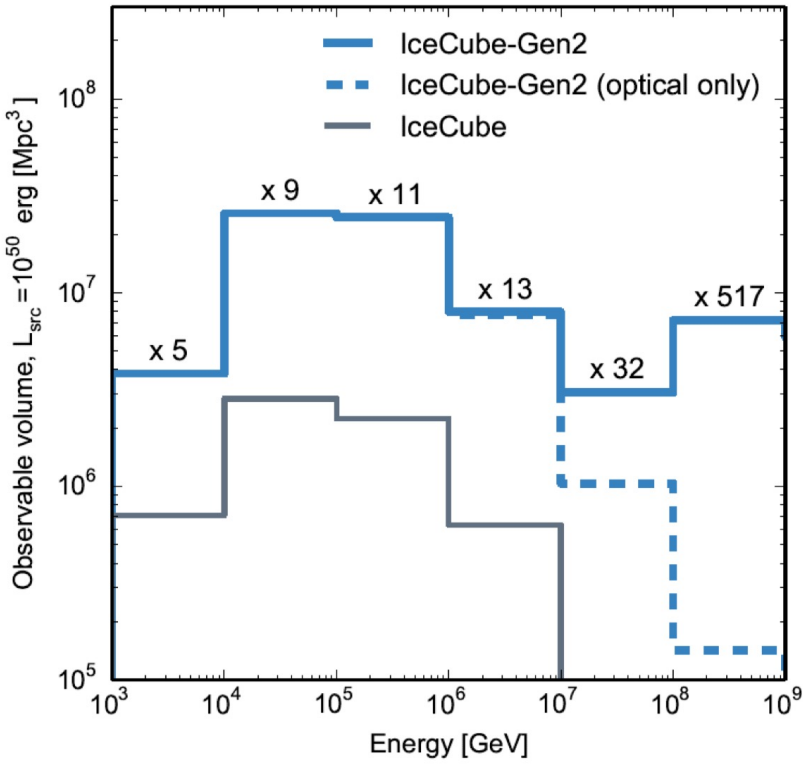
IceCube-Gen2



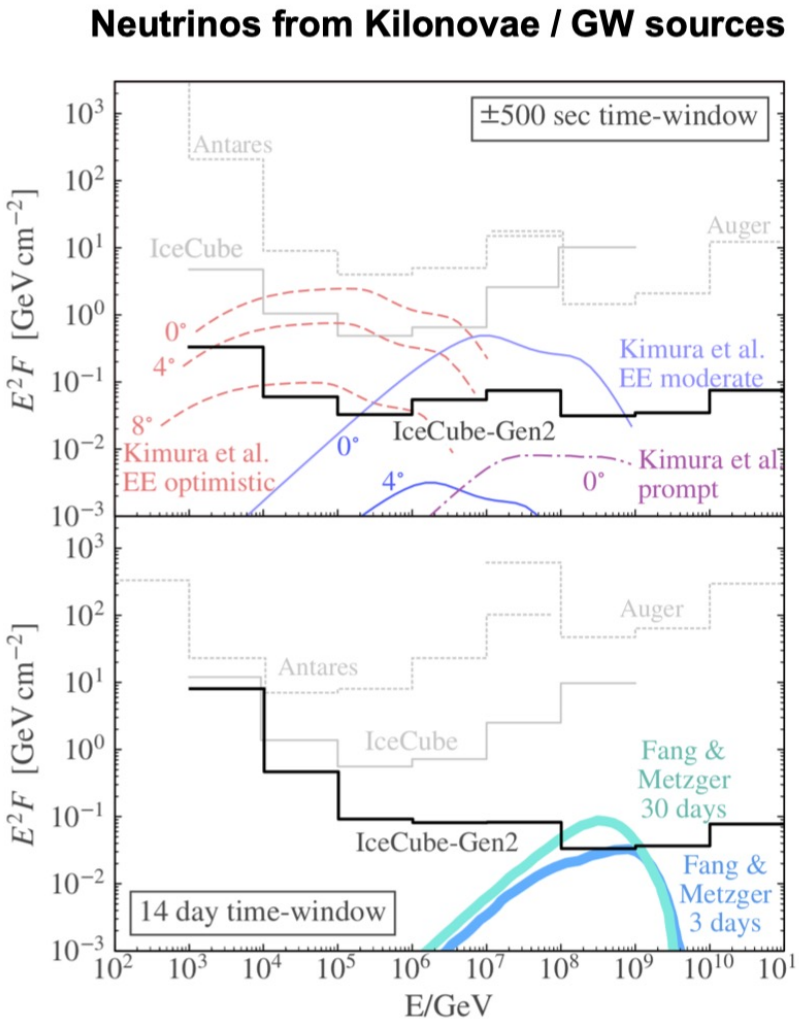
IceCube-Gen2 Science Highlights

Resolving the high-energy sky from TeV to EeV energies

~10x the number of sources
~5x fainter sources



Understanding cosmic particle acceleration through multimessenger observations



Our Groups Activities towards Gen2

Hardware development

1. Development of an Wavelength-Shifting Optical Module
2. Development of advanced electronics for radio detection of neutrinos
3. Development of wind turbines for polar conditions
   - with engineering department , battery testing -> full power system

sponsored by VR-RFI

also sponsored by Carl Tryggers

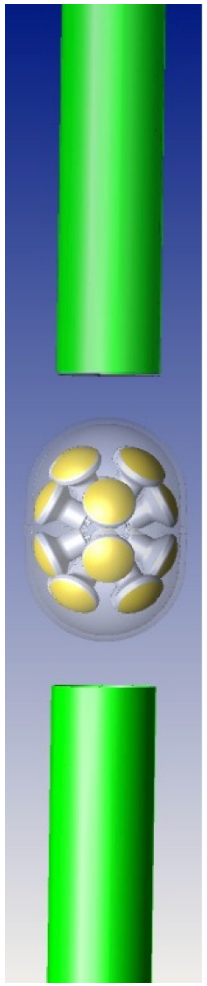
Leadership positions

- L3 lead: Deep cables development with Swedish industry
- L3 lead: Radio detector commissioning
- Radio simulations lead
- L4 lead: passive optical modules
- BSM WG convener
- Supernova WG convener
- Calibration WG convener
- Publication committee
- IceCube EXEC board

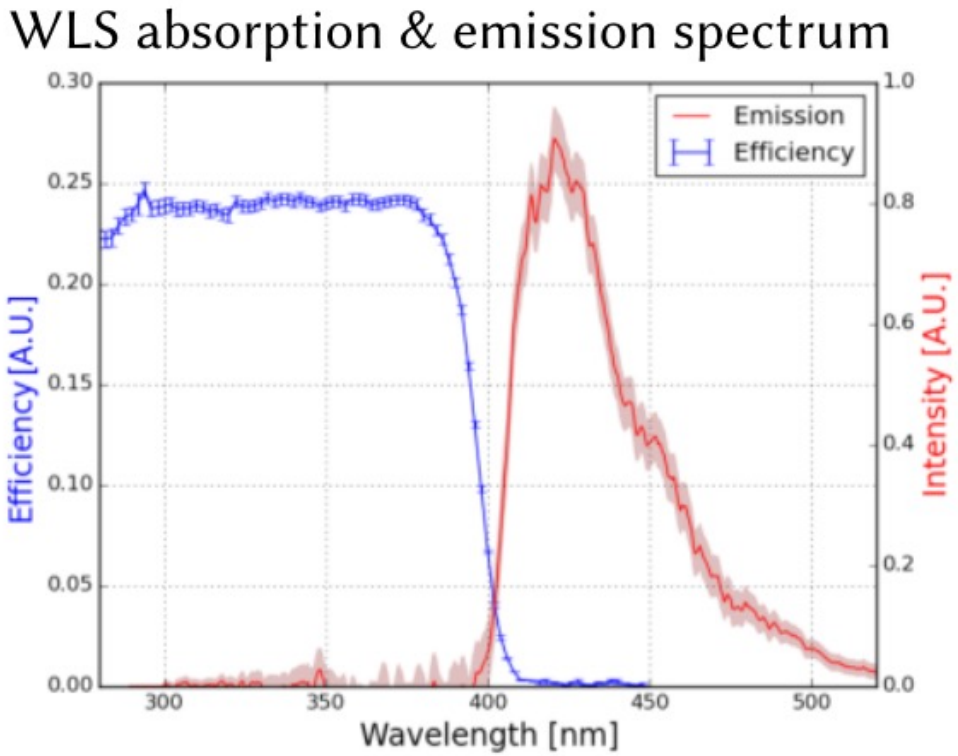
IceCube

Wavelength-shifting devices: maximize the photon collection

ACOM: Wavelength-shifting paint with interior photosensors



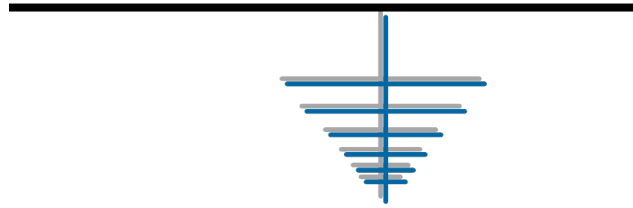
WOMTrap: Wavelength-shifting paint on passive tubes that guide light to existing photosensors

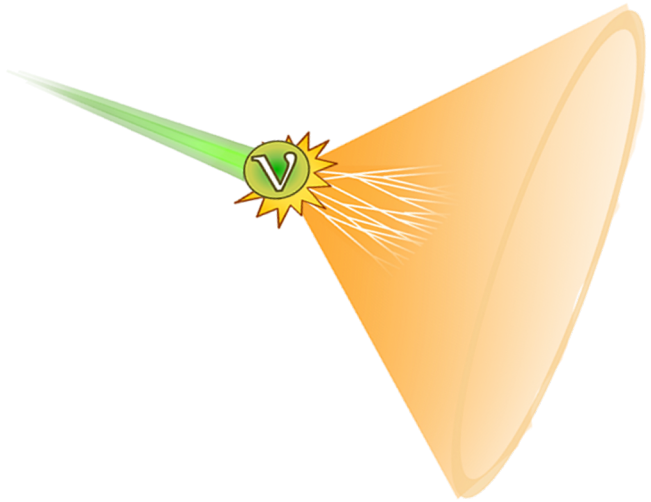


Absorbs the lower wavelengths of the Cherenkov spectrum and reemits at wavelengths that match photosensor sensitivity

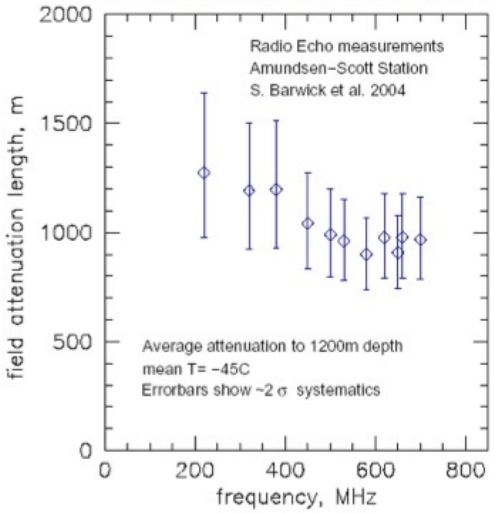
Radio Detection of Neutrinos

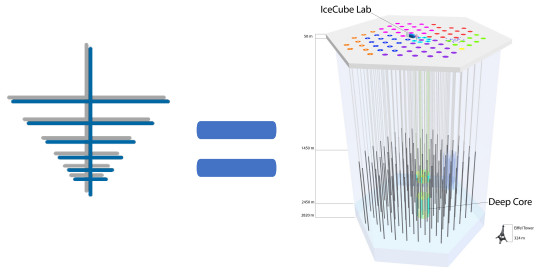
- Askaryan effect: Time varying negative charge excess in the shower front
- Cherenkov-like time compression effect
- In ice: arccos(1/n) = 56 deg





A single radio station has O(1km³) effective volume





No neutrino detected yet with a radio detector because current detectors are too small but

- Askaryan pulse measured in lab
- Feasibility shown with cosmic-ray detectors

Experimental Landscape - In-Ice Radio Detection

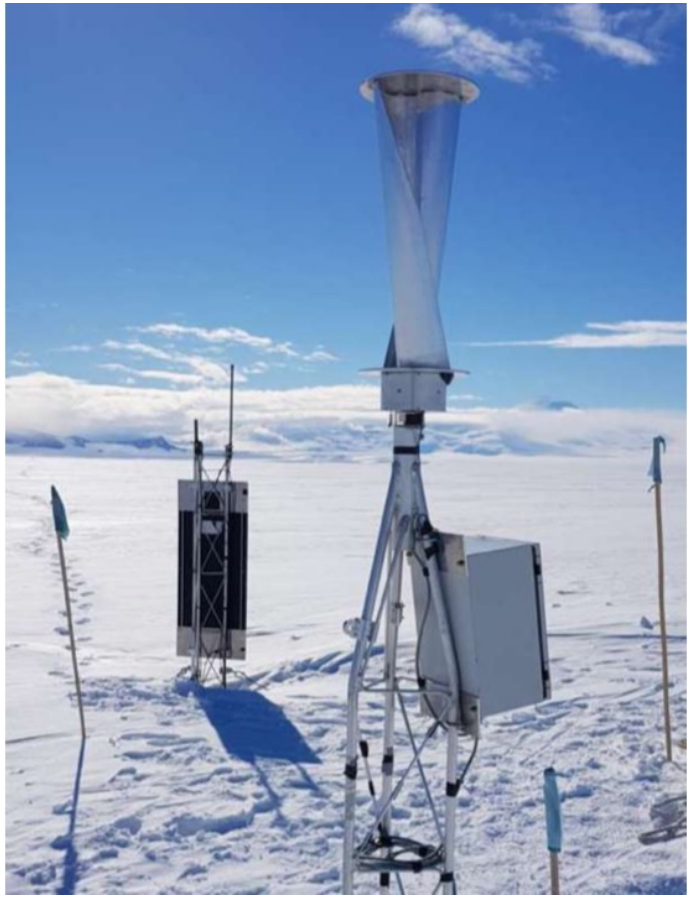
ARIANNA test bed*
- 12 shallow stations at Moore's Bay + South Pole

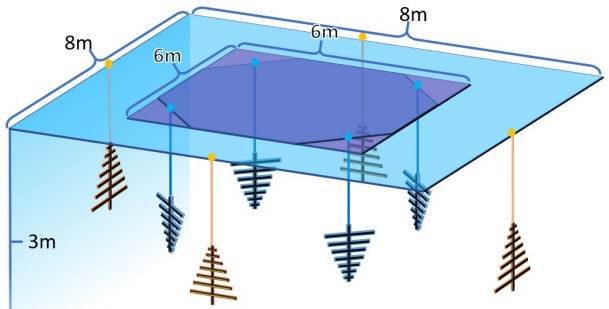
ARA
- 5x 200m deep stations at South Pole

Radio technology developed and verified; hardware proven reliable

Swedish involvement
- data analysis
- novel trigger system
- windgen

Windgen on Ross Ice Shelf (developed by Uppsala)





ARIANNA

past

now

future

*: Experiments with Swedish involement

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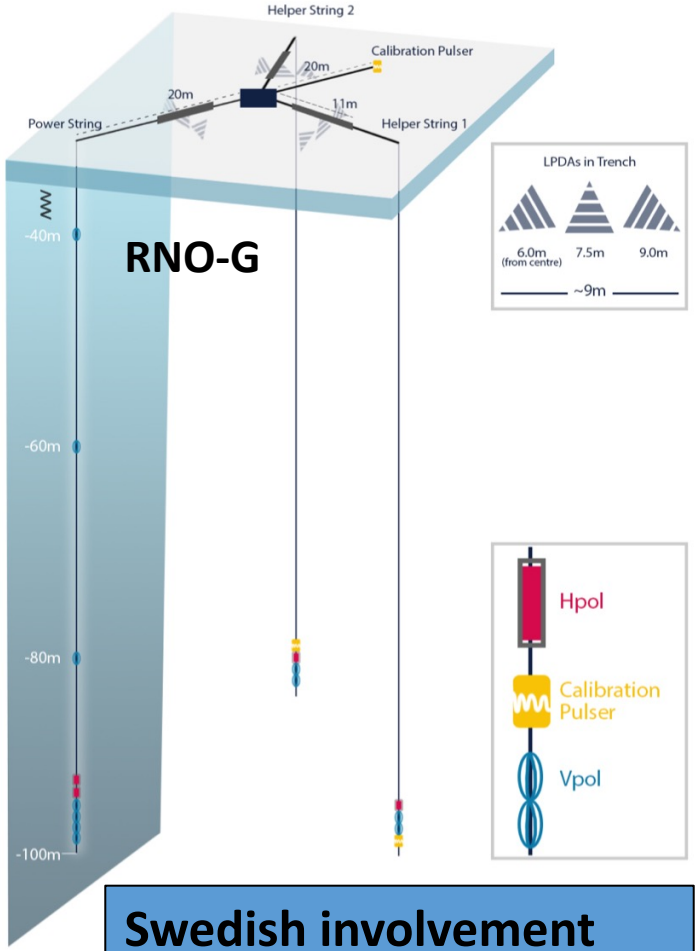
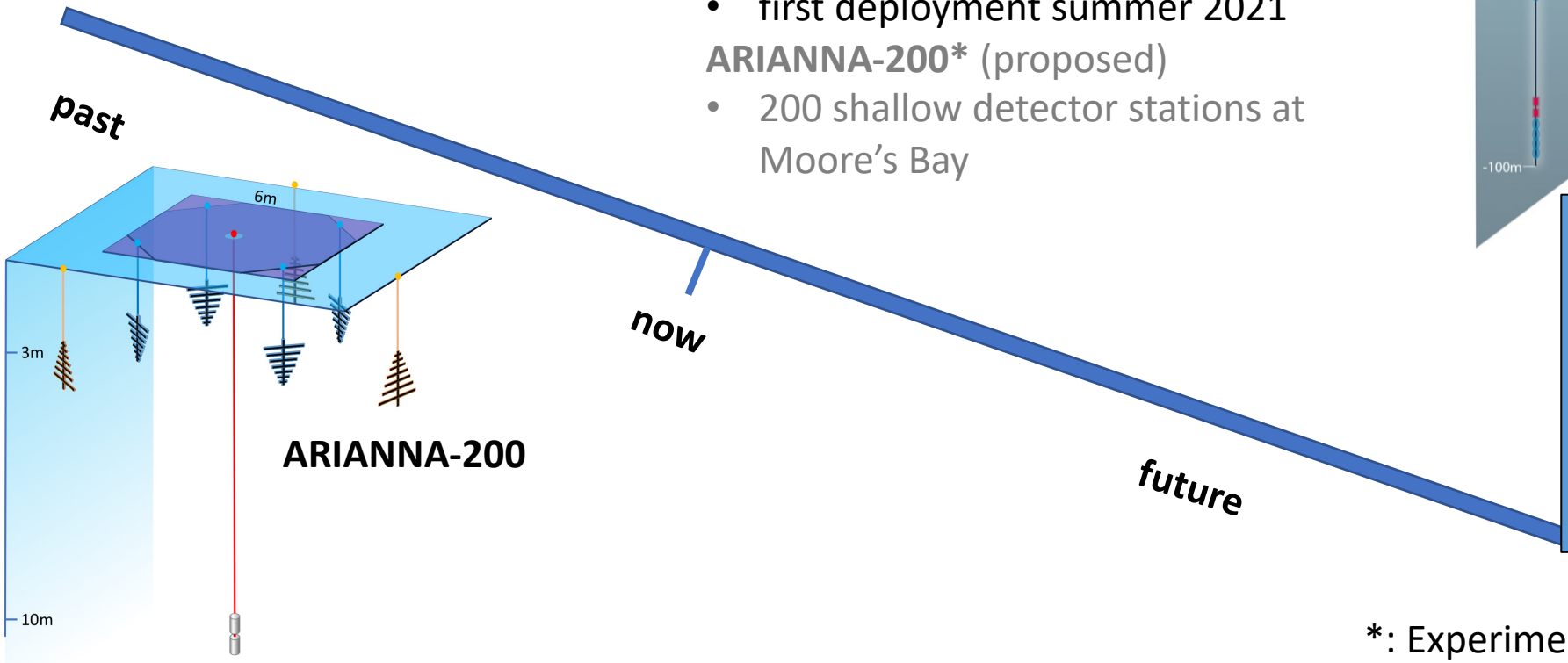
RNO-G*
- 35 detector stations in Greenland
- first deployment summer 2021

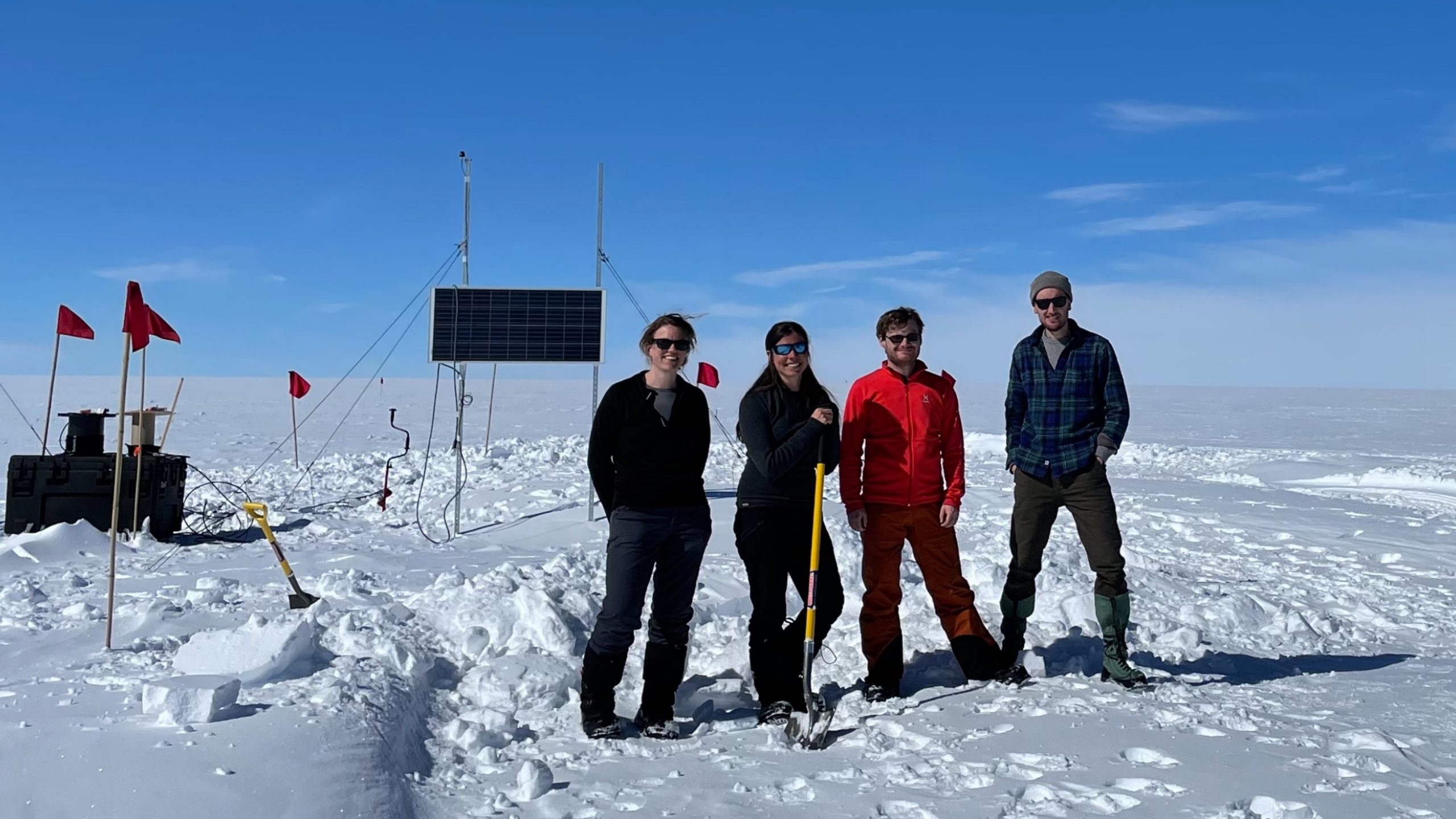
ARIANNA-200* (proposed)
- 200 shallow detector stations at Moore's Bay





Swedish involvement
- windgen
- MC simulation
- event reconstruction
- calibration database
- trigger improvements

*: Experiments with Swedish involement



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Swedish involvement
- simulation lead
- event reconstruction
- L3 lead detector comissioning
- power system (windgen/batteries)

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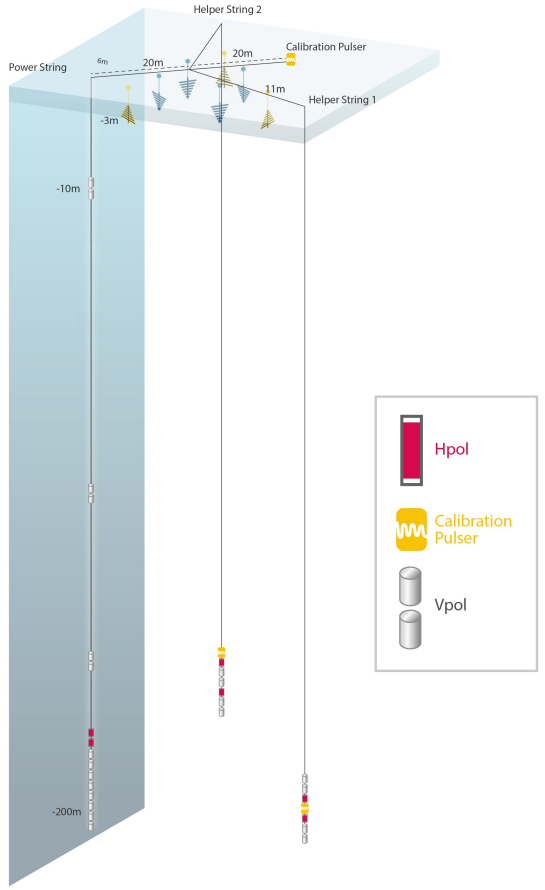
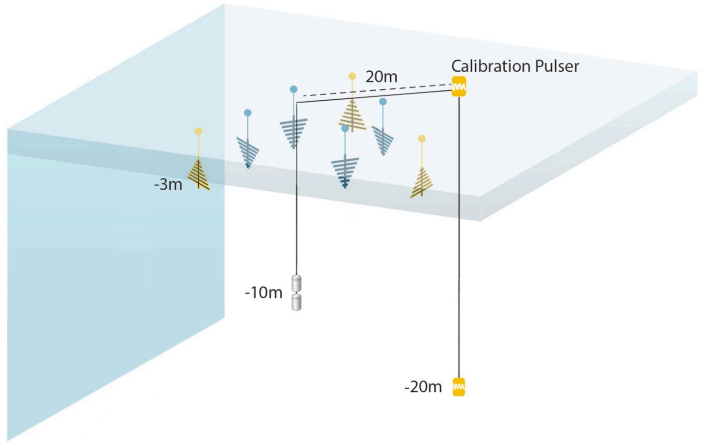


past — now — future



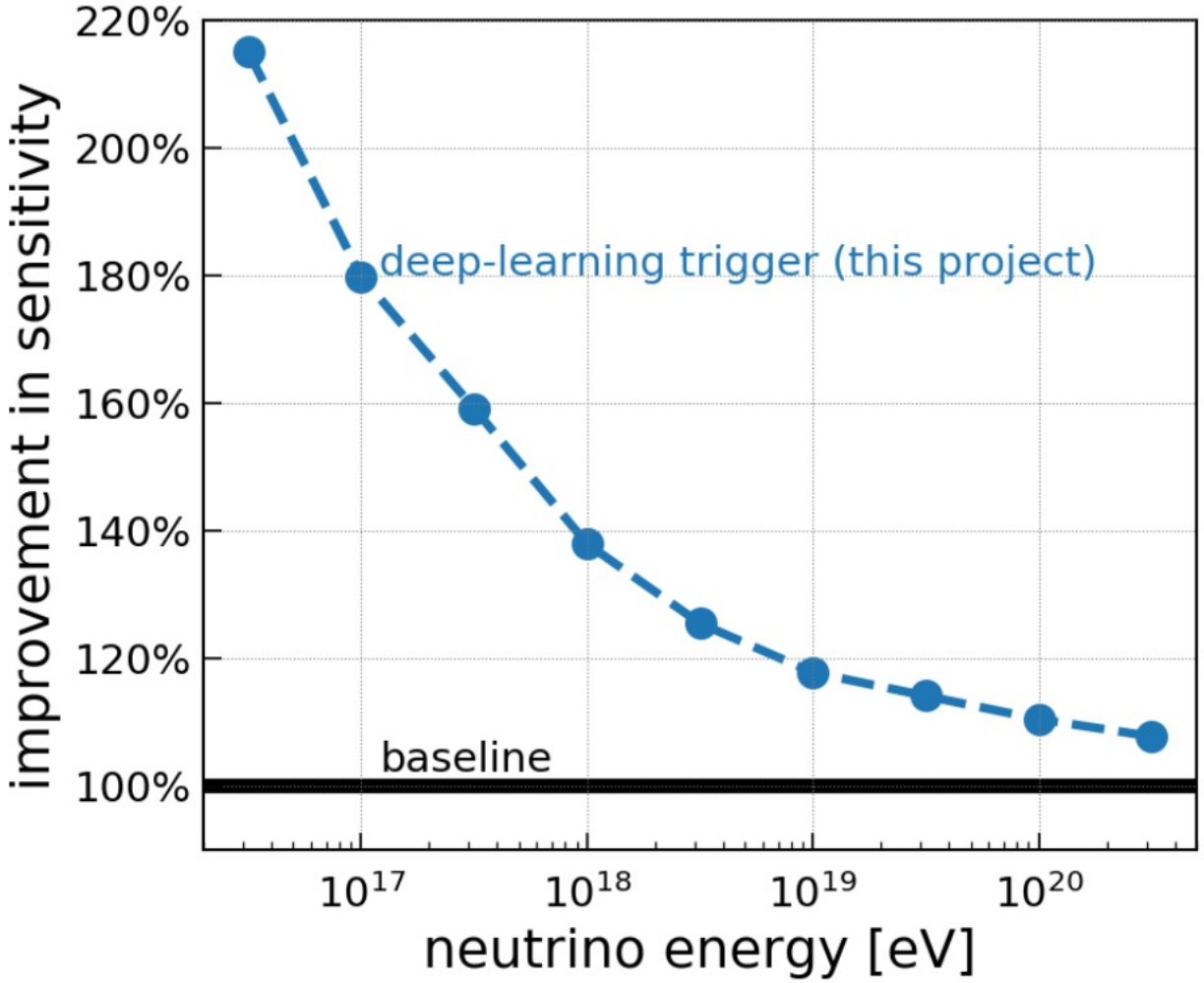
IceCube-Gen2*
- 300+ detector stations at South Pole
- hybrid array of deep and shallow stations

*: Experiments with Swedish involement

Deep Learning Trigger Development

- Trigger rate limited by triggers on thermal noise fluctuations
- Real-time rejection of thermal noise
  → lower threshold
  → larger sensitivity
- Pilot study with ARIANNA hardware
- Now: Development for RNO-G and Gen2

hiring two PostDoc/PhD students soon



Summary

- IceCube-Gen2: uniquely sensitive neutrino observatory ranging from GeV to beyond EeV in energy
- Optical component
  - 10x larger instrumented volume
  - better angular resolution
  - hardware development: improved optical modules
- Radio component
  - Involvement in ARIANNA and RNO-G
  - Increases sensitivity to EeV energies
  - hardware development: autonomous power system (windgens) + trigger development

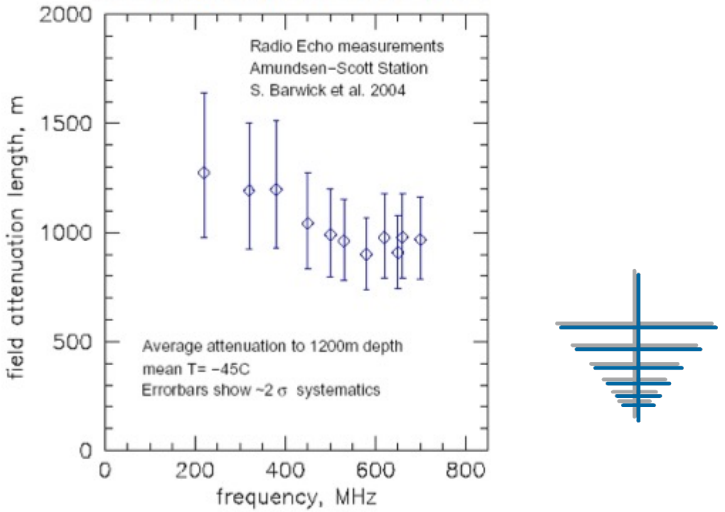
backup

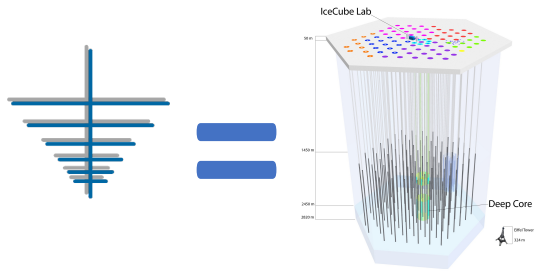
Experimental Challenges

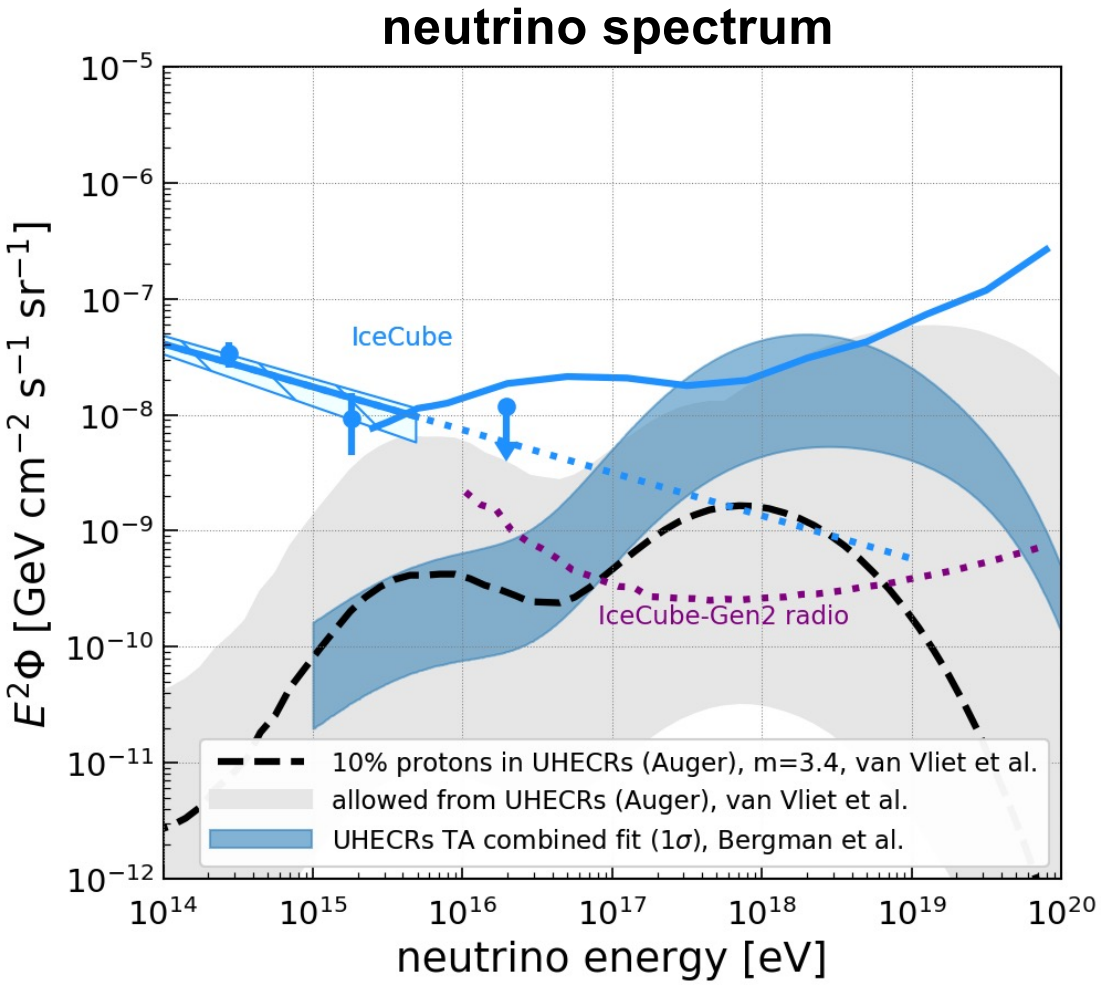
- Low interaction cross section of neutrinos
- Very low neutrino flux

→Very large volumes needed for reasonable rates

- **Solution: radio technique**
  - Large volumes at no cost: Antarctic ice
  - Ice transparent to radio waves (L ~ 1km)
  - A single radio station has 1km³ effective volume (comparable to IceCube)





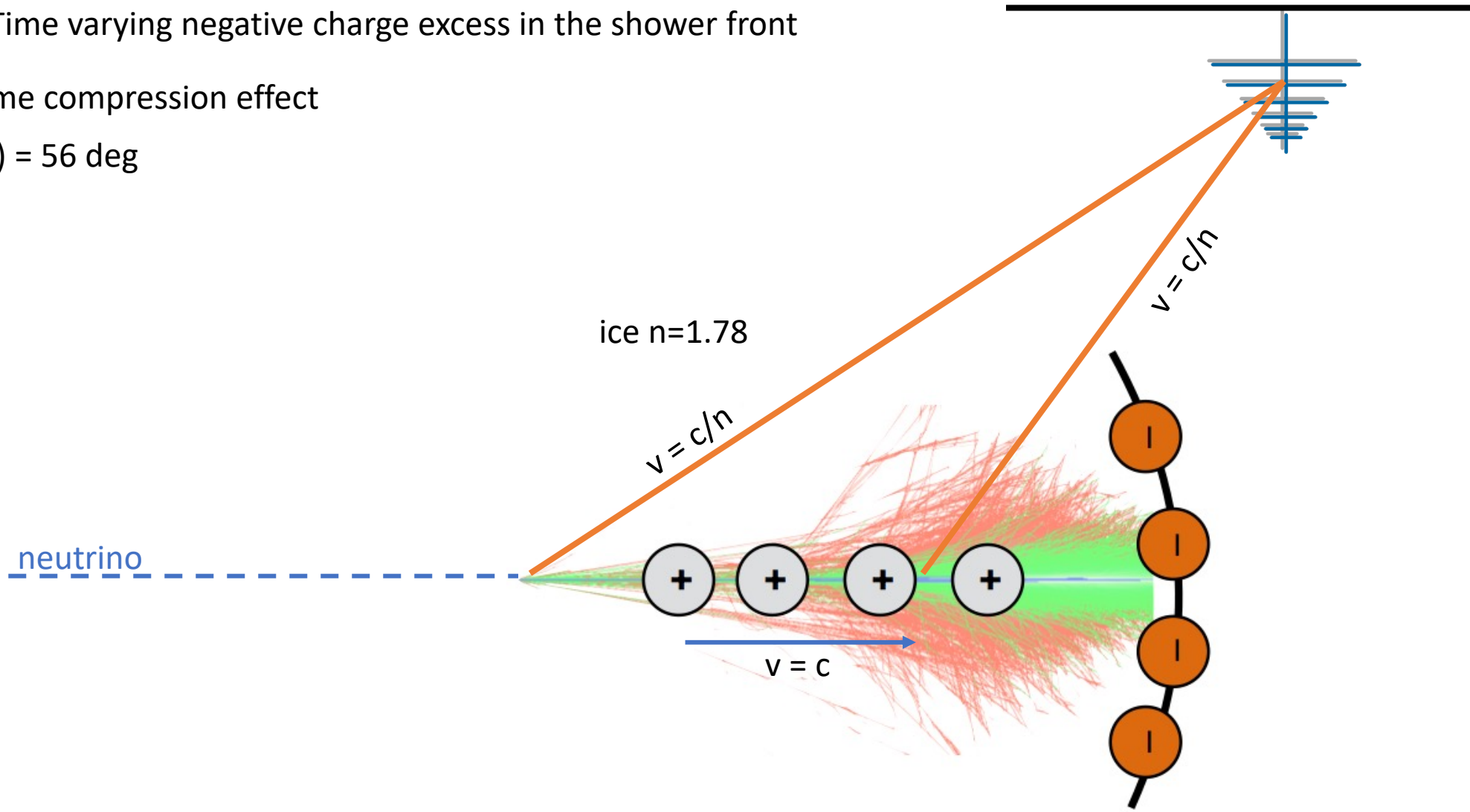


optical

radio

Radio Emission of Particle Showers

- Askaryan effect: Time varying negative charge excess in the shower front
- Cherenkov-like time compression effect
- In ice: arccos(1/n) = 56 deg



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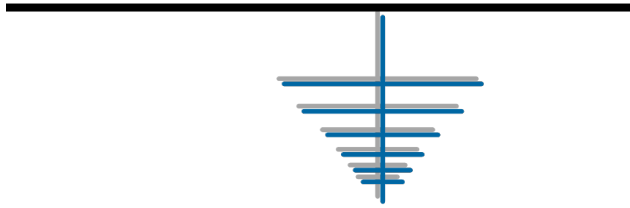

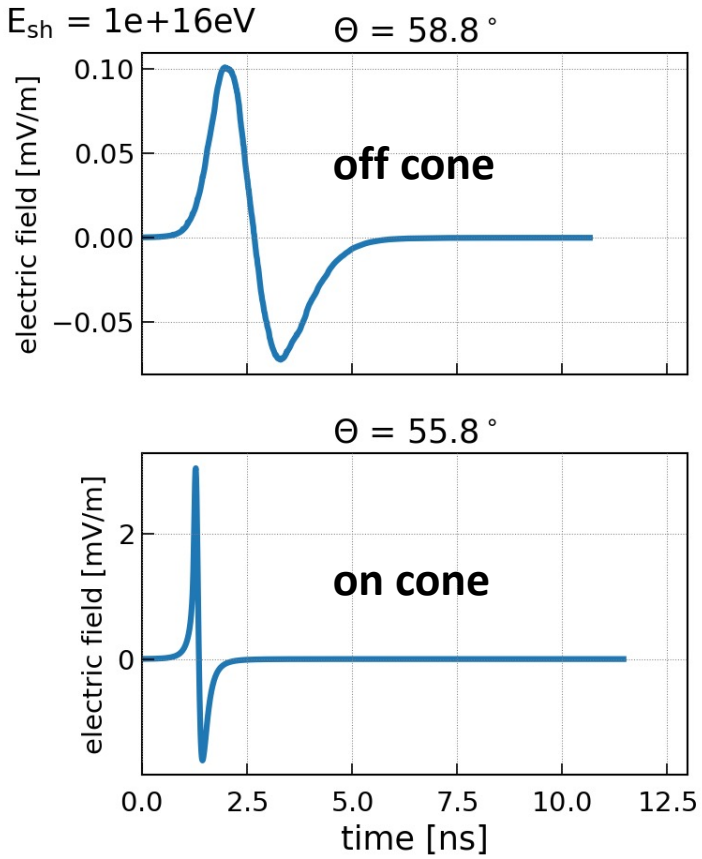

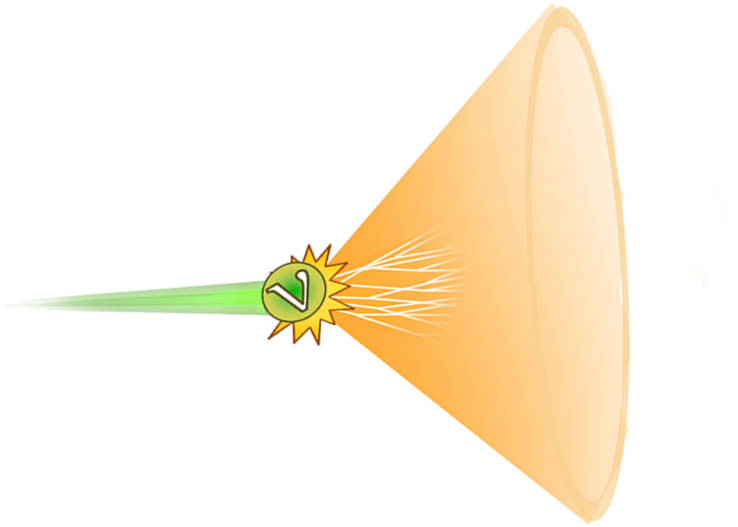

No neutrino detected yet with a radio detector because current detectors are too small but

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- Feasibility shown with cosmic-ray detectors

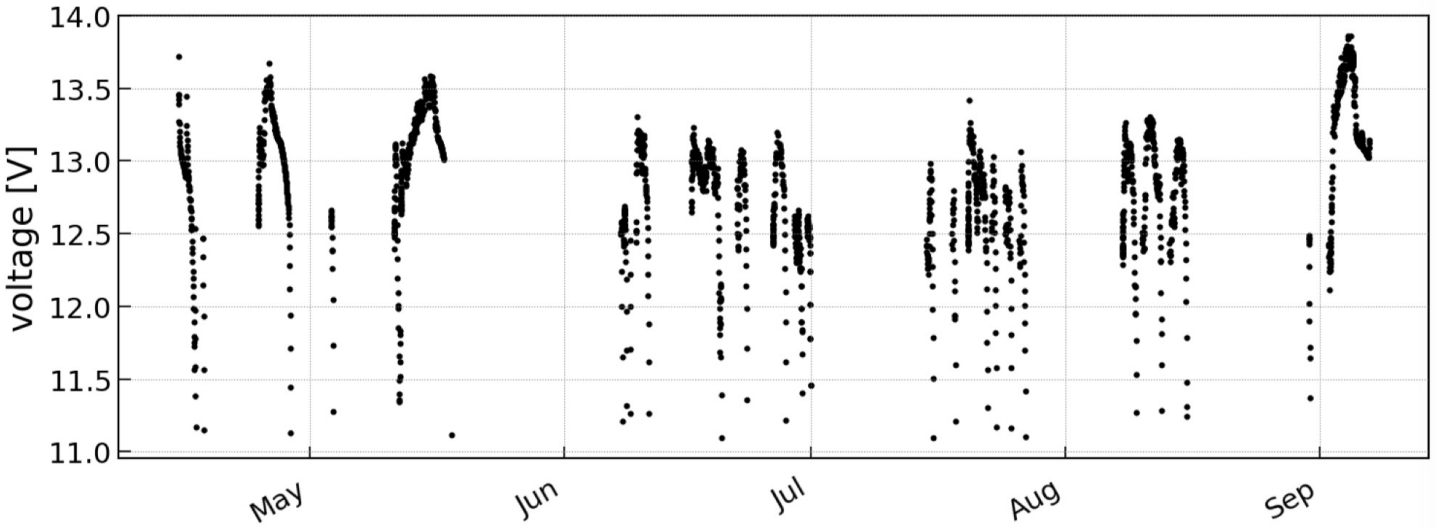
Detector sites

- Requirement: A lot of cold ice
  - the colder the larger the attenuation length
- South Pole (ARA, IceCube-Gen2; L~1-2km)
- Ross Ice Shelf (ARIANNA; L~0.5km)
- Greenland (RNO-G; L~1km)

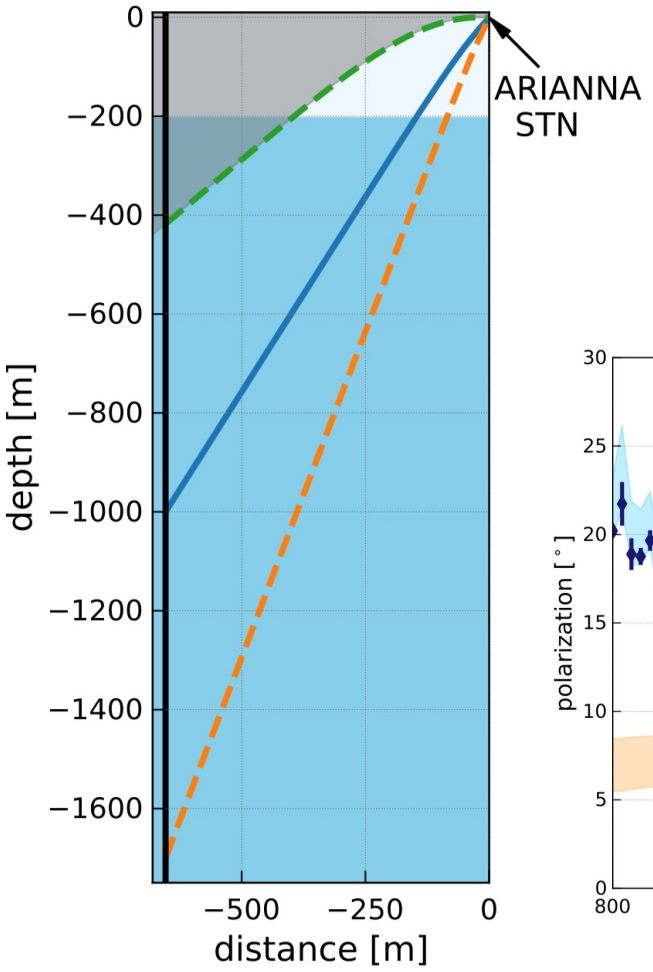
A. Nelles for the ARIANNA Collaboration,
Proc. 36th ICRC 2019, Madison, Wisconsin, USA,
PoS(ICRC2019)968

Development of wind power system

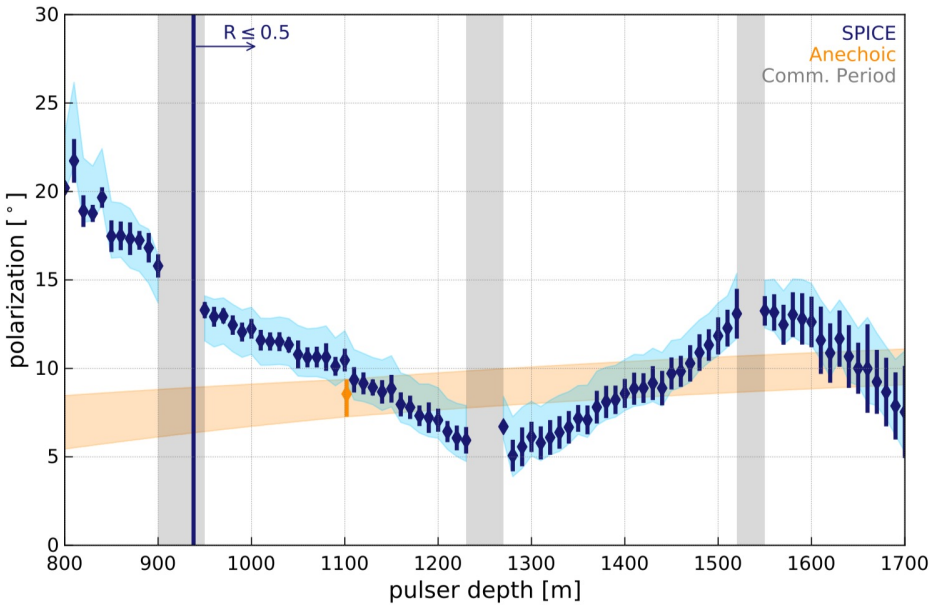
- Wind power system required for dark winter months
- Pioneered at Uppsala
  - prototype (Savant 2) survives harsh Antarctic conditions and powers station for ~50% of the time
  - Savant 3: 2x larger -> 85% uptime at Moore's Bay
  - Savant 4: 5x larger -> 80% uptime in Greenland



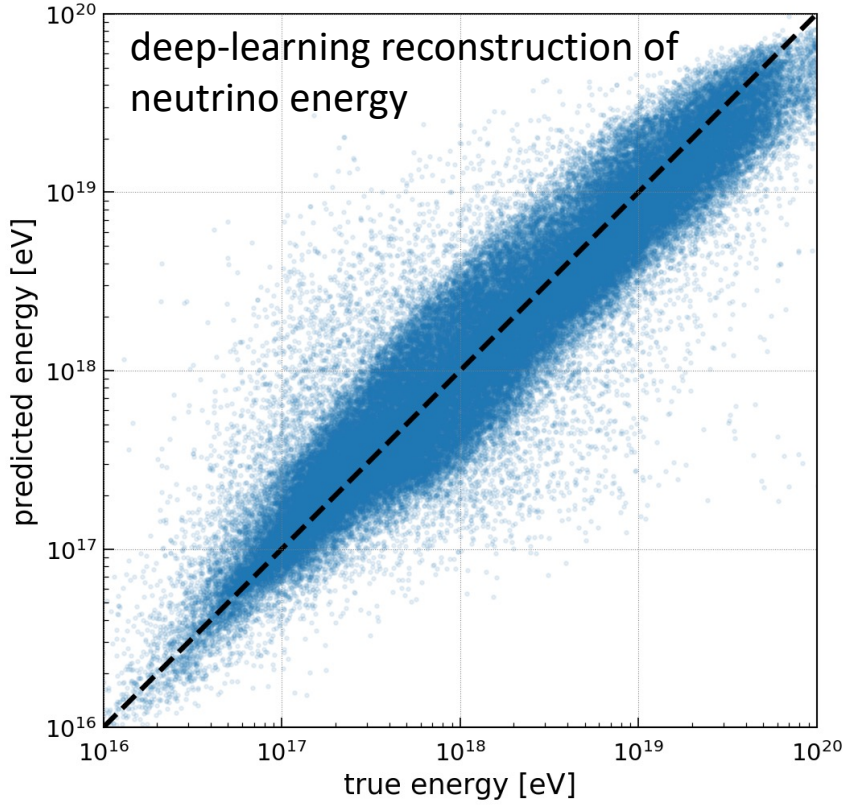
Event Reconstruction



In-situ test of angular and polarization reconstruction

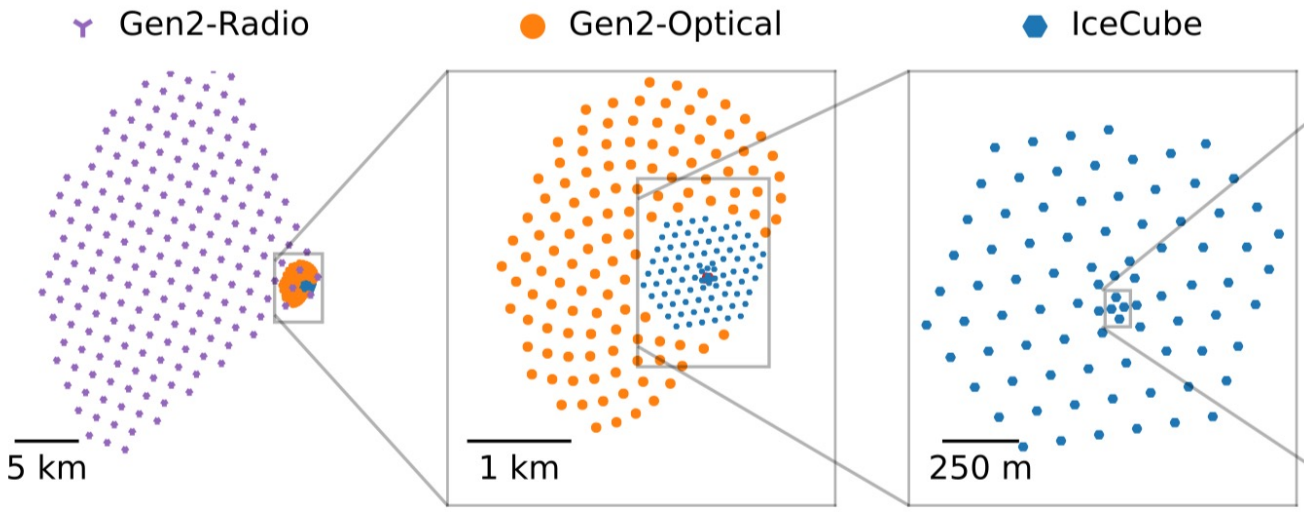


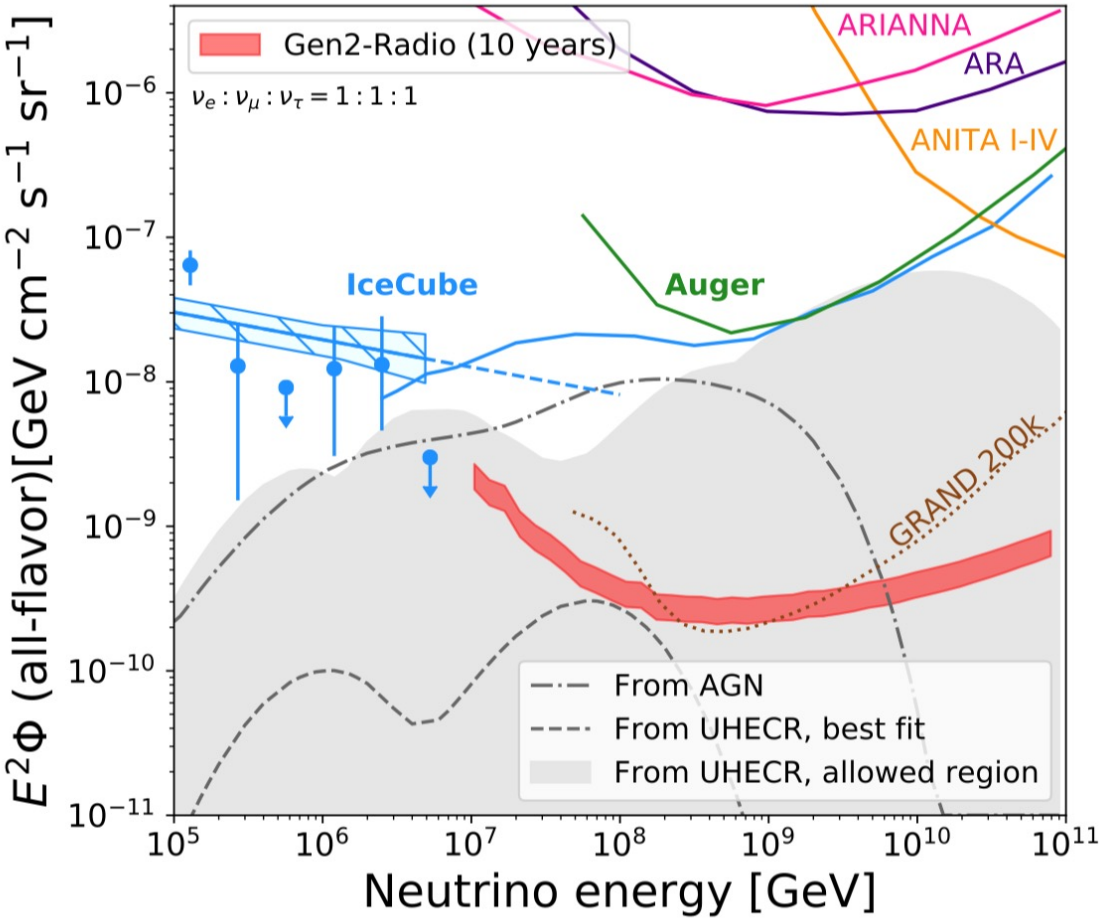
- software development
- simulation (NuRadioMC) and reconstruction (NuRadioReco)
- open-source on github

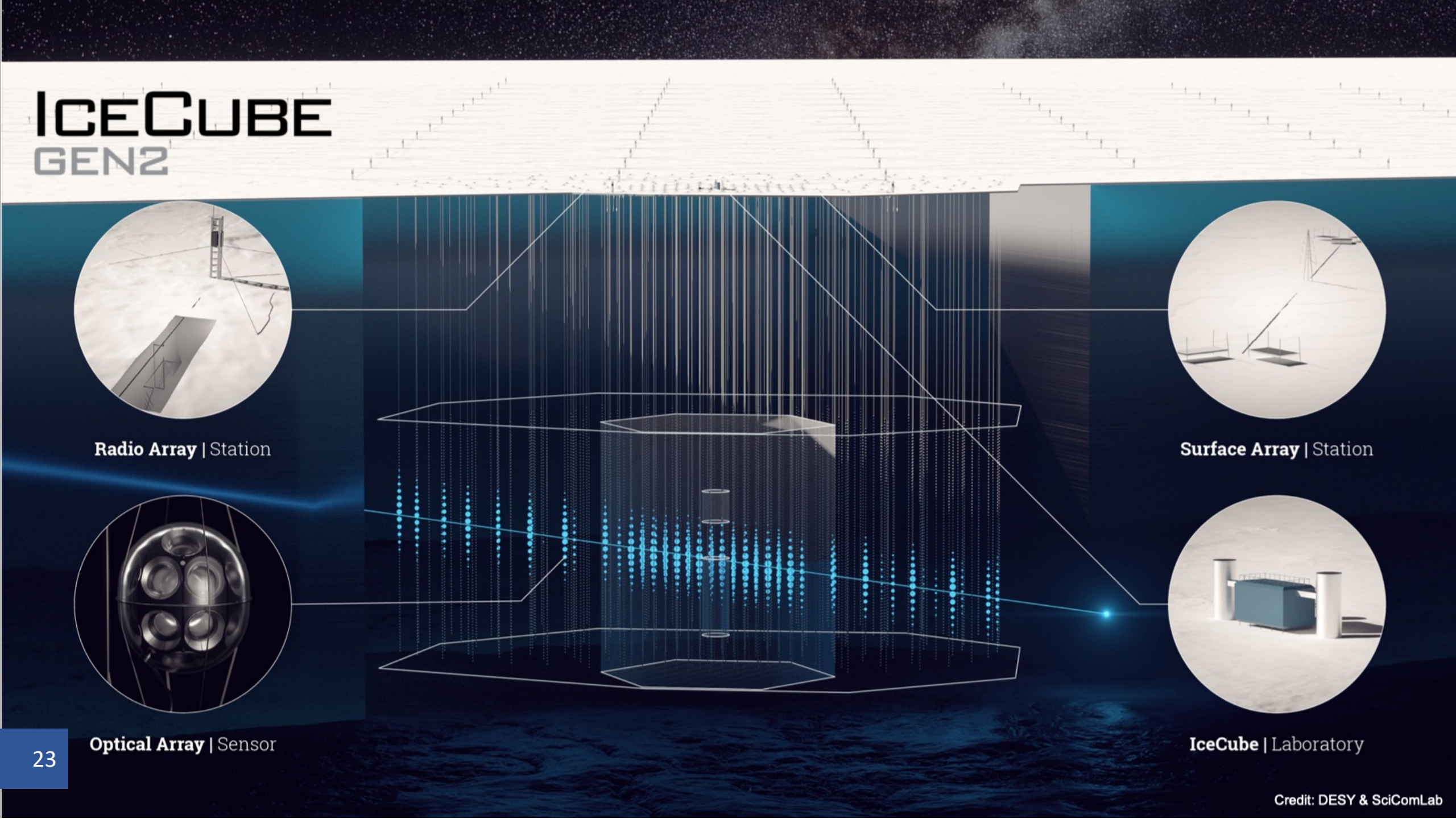


The future part II: IceCube-Gen2

- Large radio detector is part of IceCube-Gen2 vision
  - to increase sensitivity for E>10^{16}eV
- >200 radio detector stations
- if funded, start of construction in 2025






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