Radio Detection of High-Energy Neutrinos

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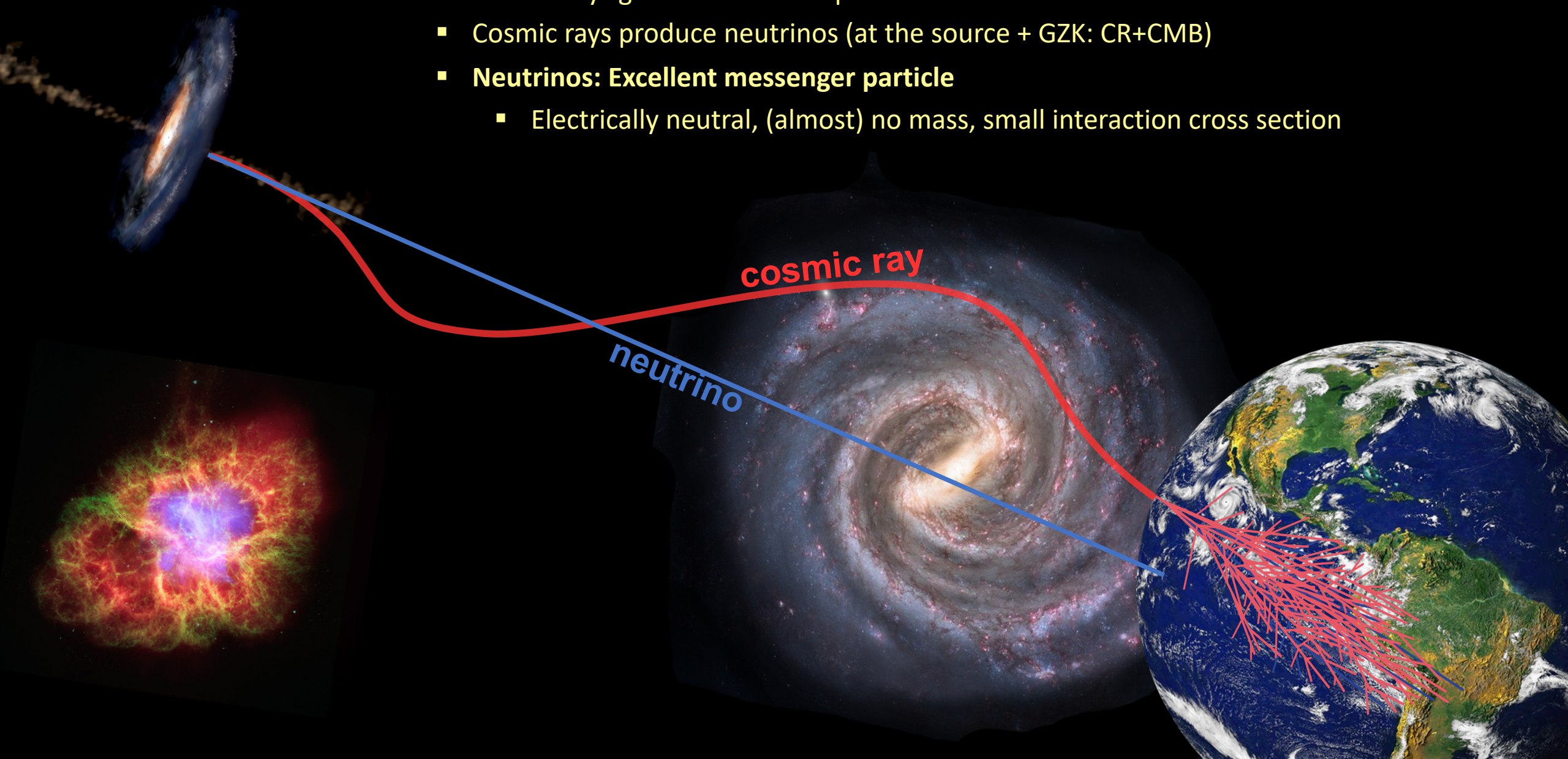
The High Energy Universe

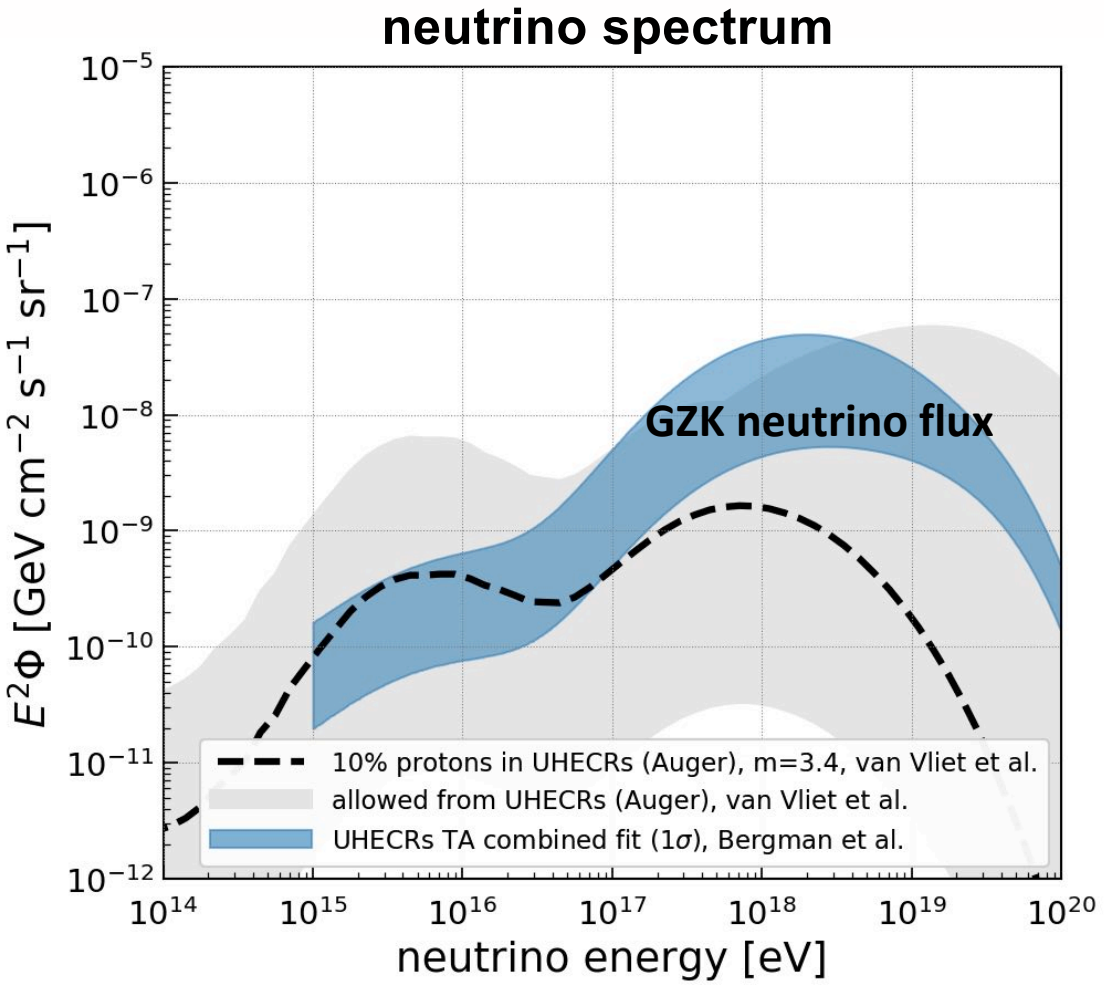
- Cosmic rays gets accelerated up to 10^{20}eV
- Cosmic rays produce neutrinos (at the source + GZK: CR+CMB)
- **Neutrinos: Excellent messenger particle**
  - Electrically neutral, (almost) no mass, small interaction cross section



Experimental Challenges

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

→Very large volumes needed for reasonable rates



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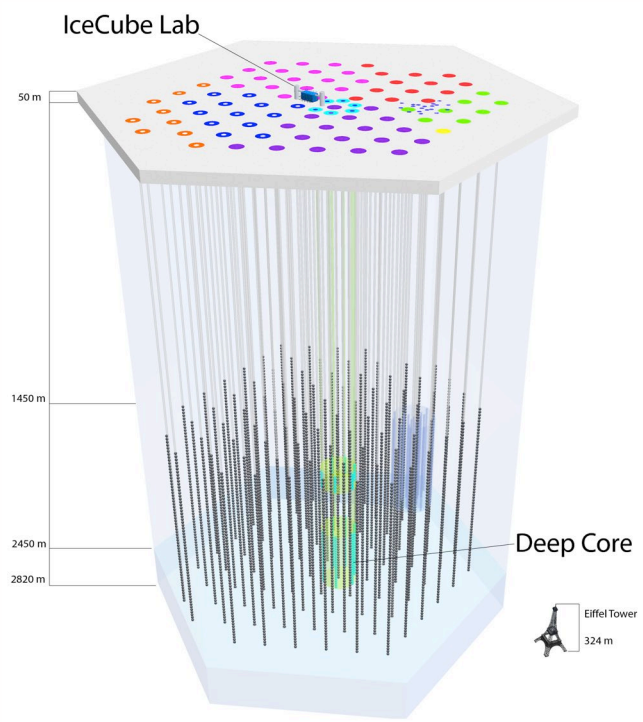
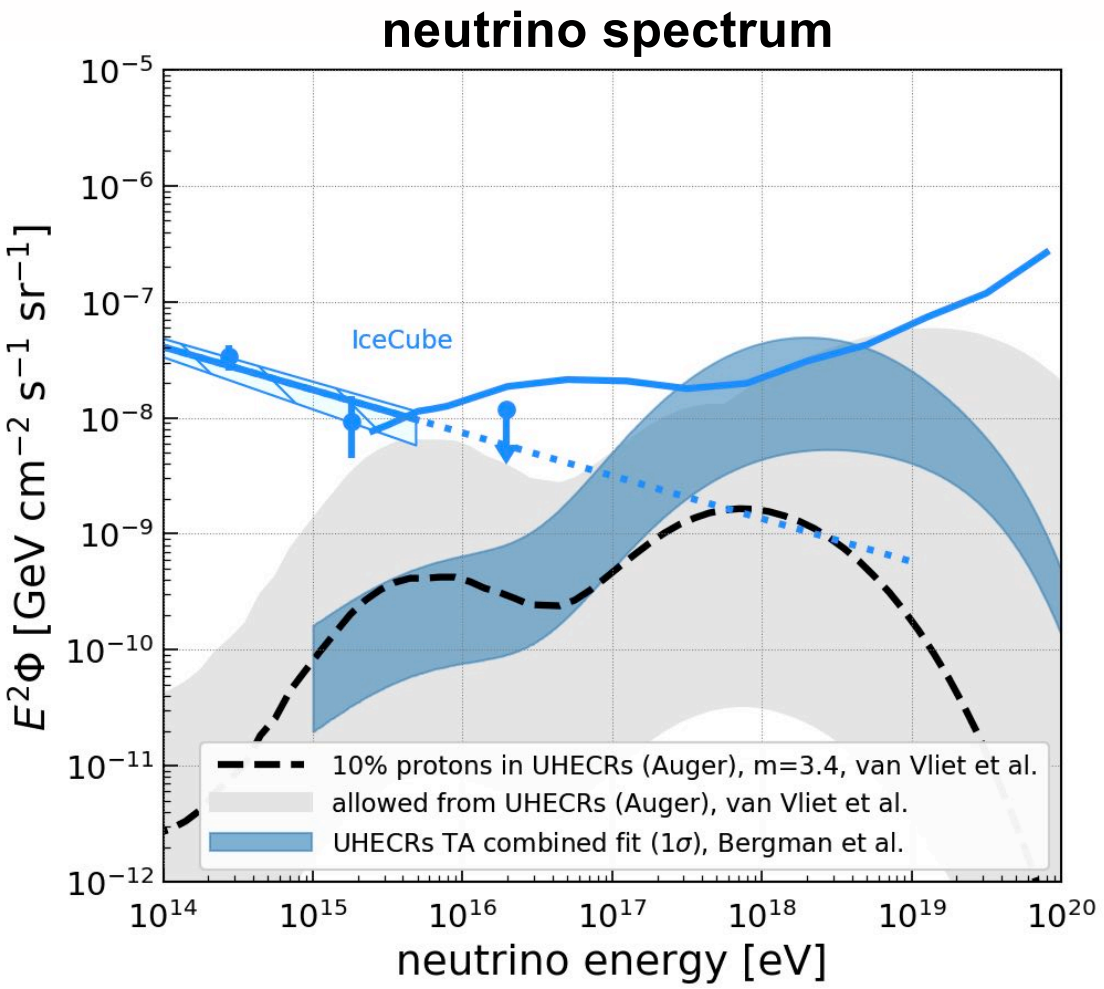




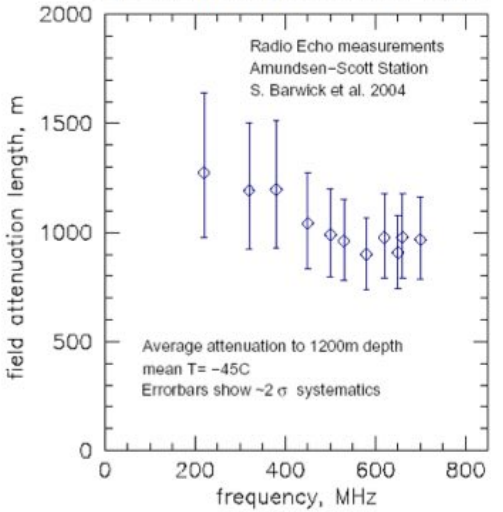
optical

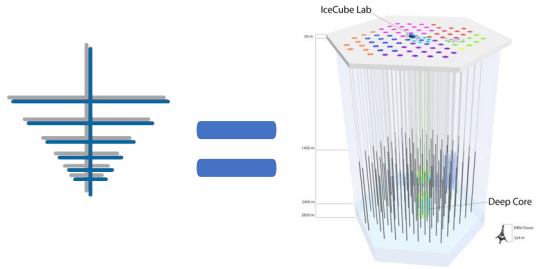
Experimental Challenges

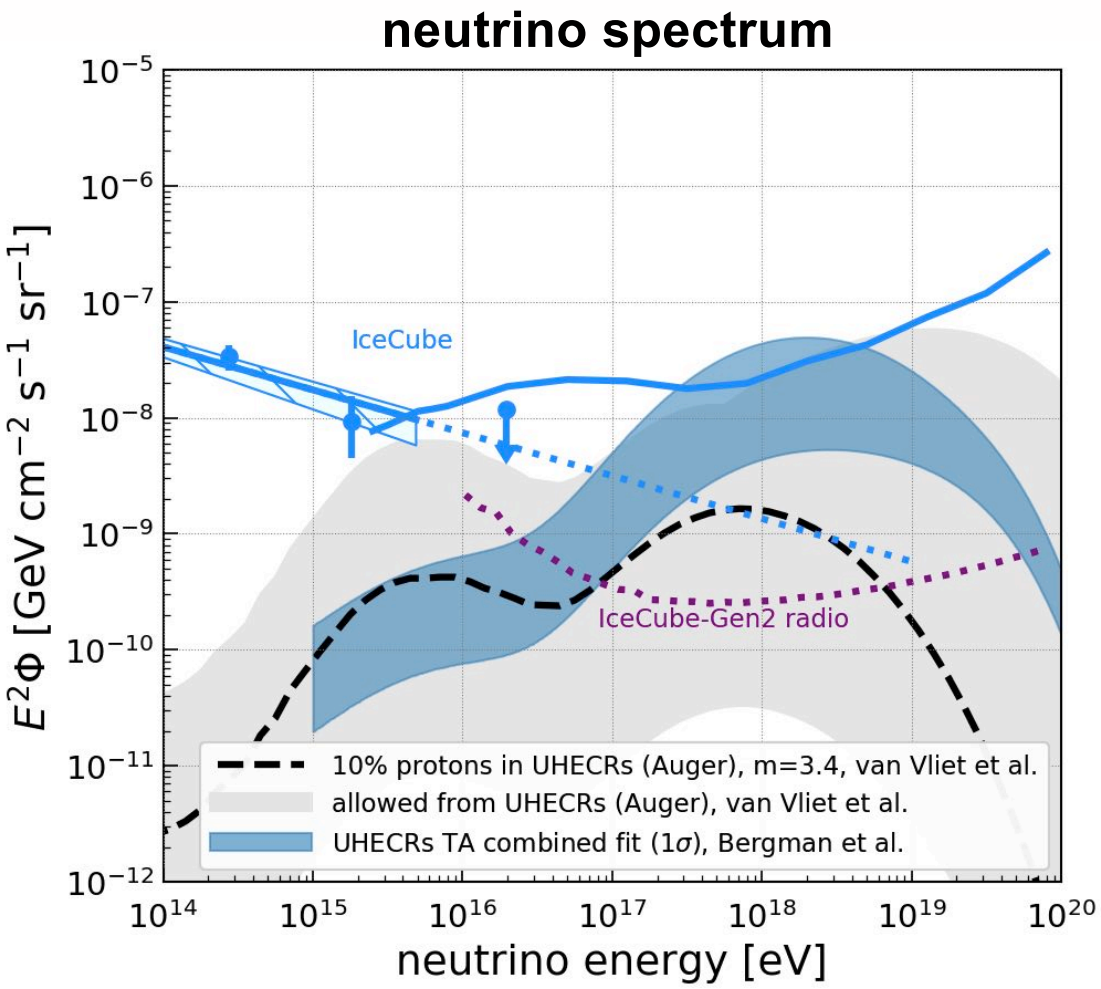
- Low interaction cross section of neutrinos
- Very low neutrino flux

→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)





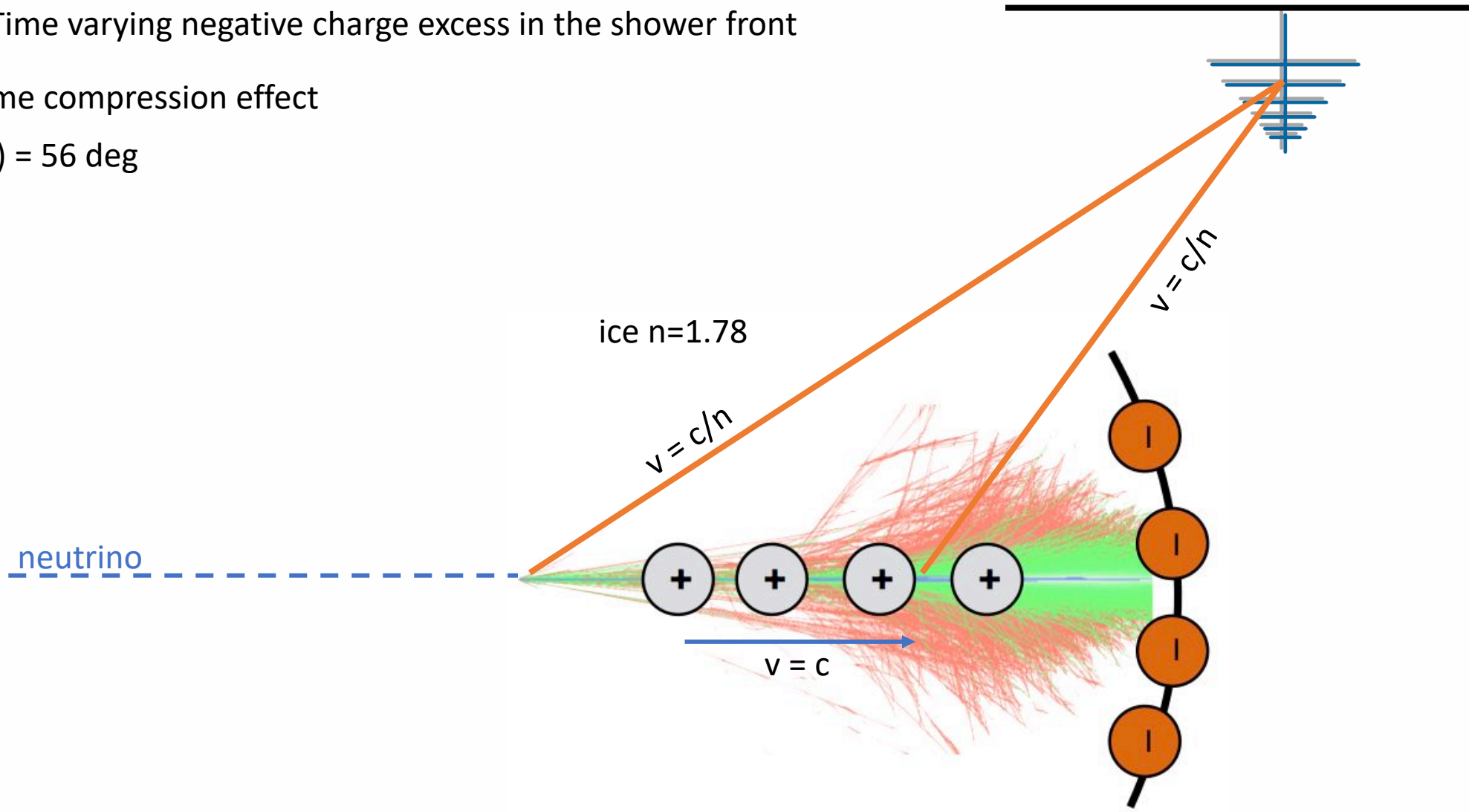


optical

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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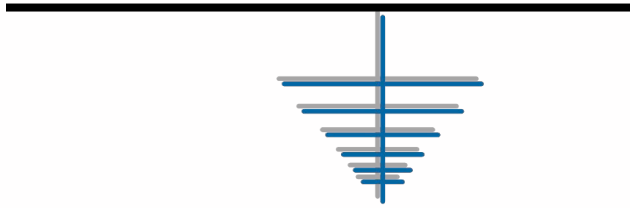
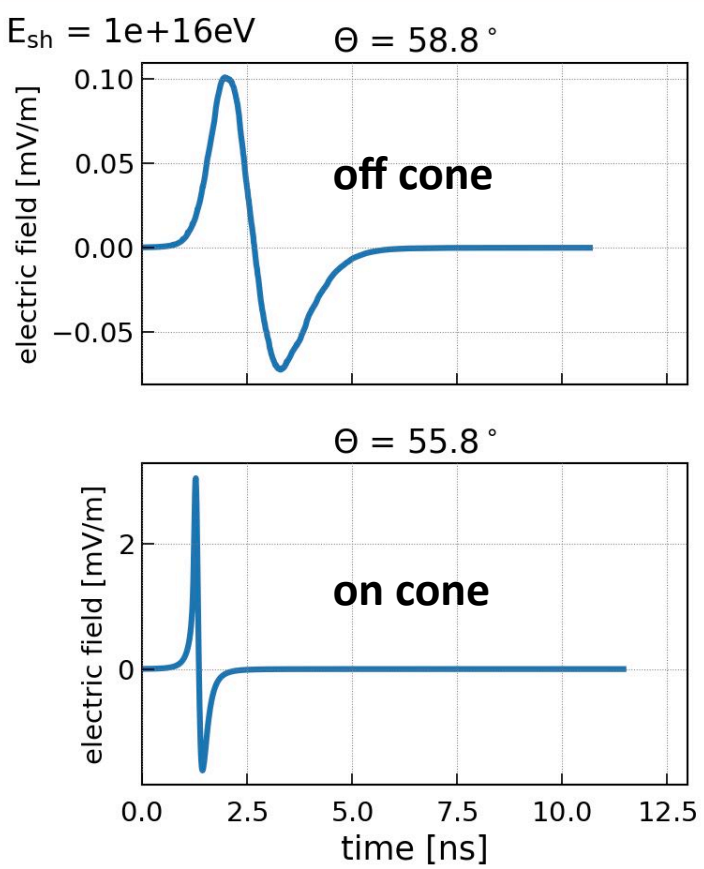
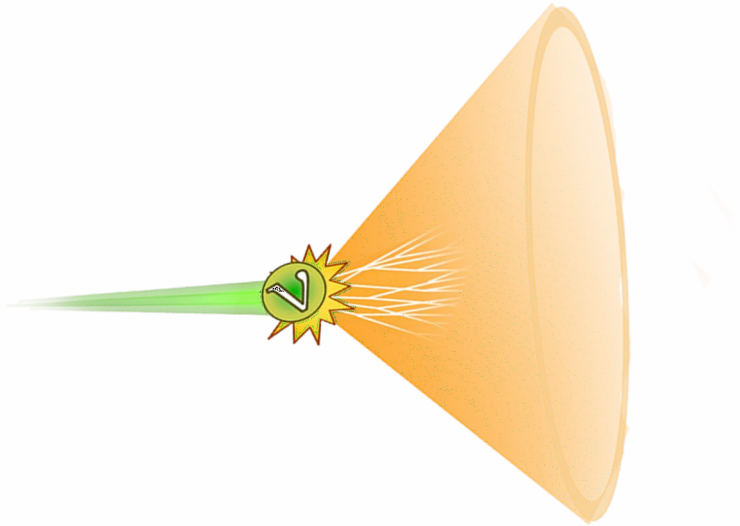




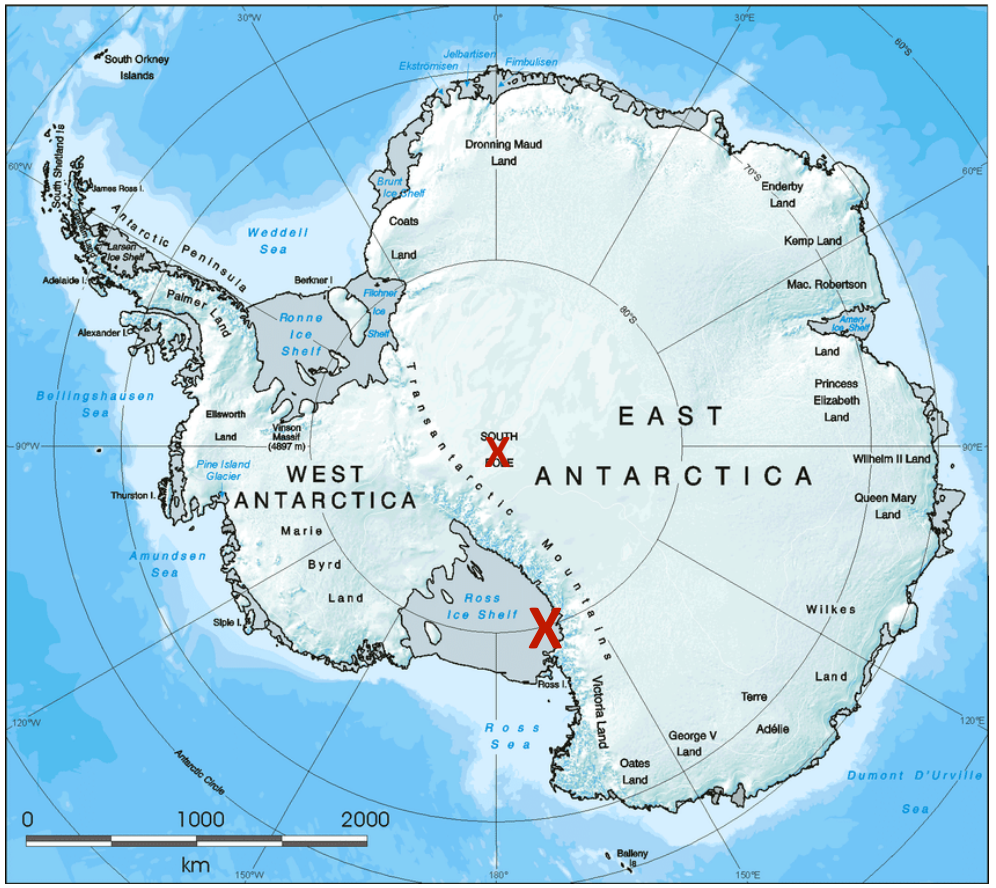


No neutrino detected yet with a radio detector because current detectors are too small but

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

Detector sites

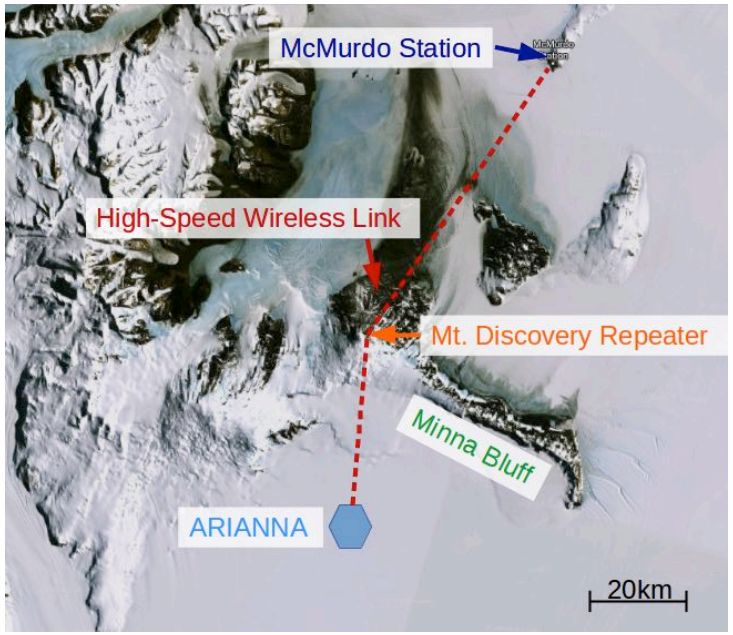
- Requirement: A lot of cold ice
  - the colder the larger the attenuation length
- South Pole (ARA, IceCube-Gen2; L~1-2km)
- Ross Ice Shelf (ARIANNA; L~0.5km)
- Greenland (RNO-G; L~1km)

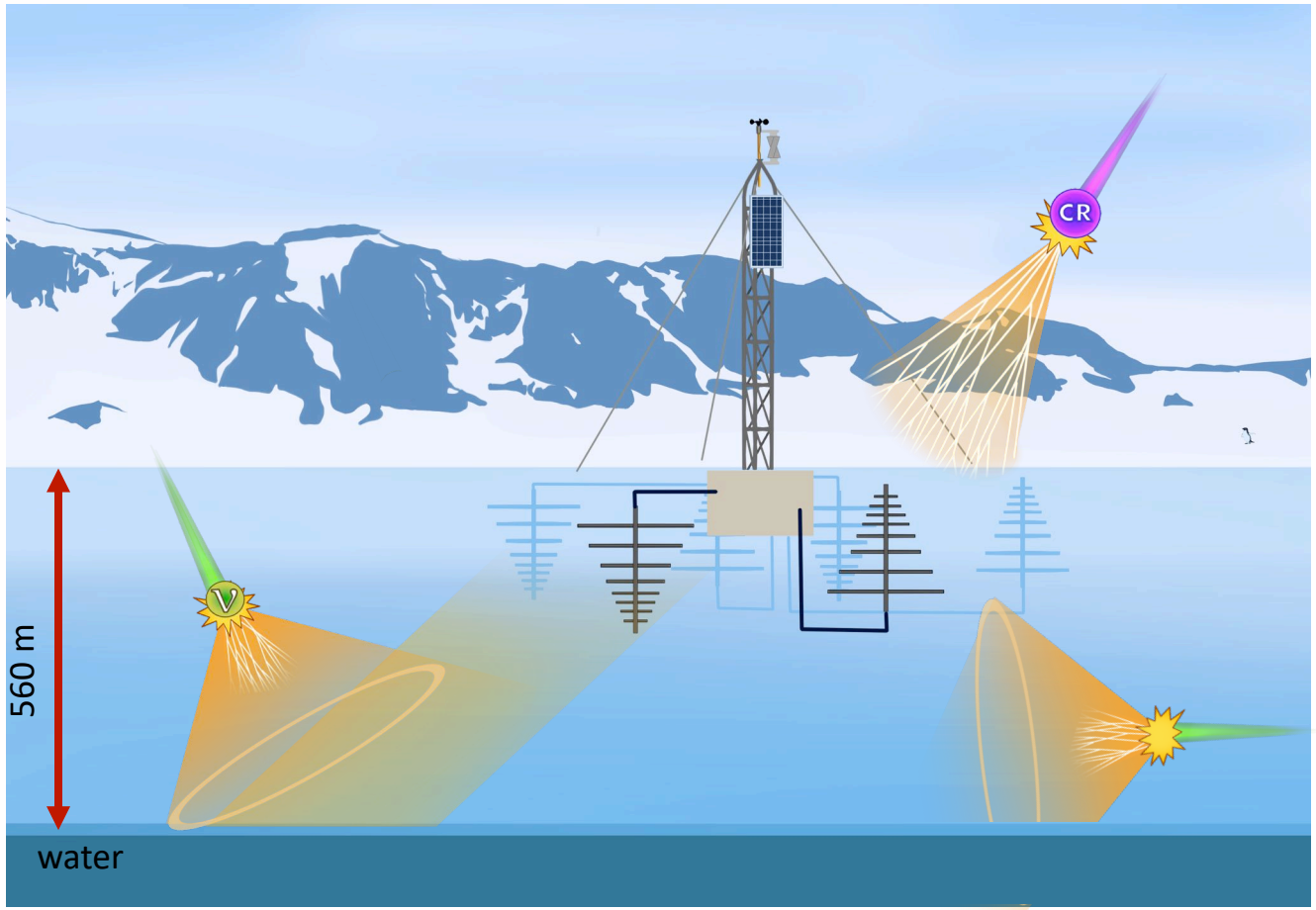


The ARIANNA detector on the Ross Ice Shelf

The ARIANNA detector on the Ross Ice Shelf

- **Moore's Bay on Ross ice shelf (-79deg)**
  - 10 autonomous stations



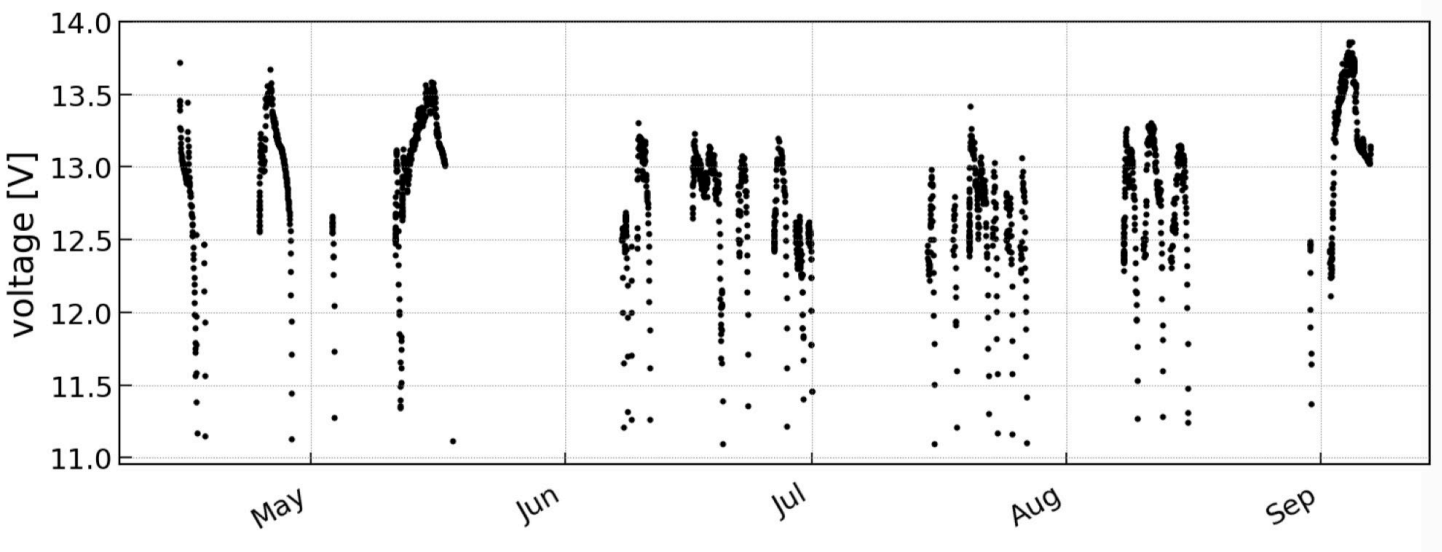


- Size 1% of required size
  - no neutrino measured yet but
- Hardware proven reliable
- **Technology ready for large scale detector**

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

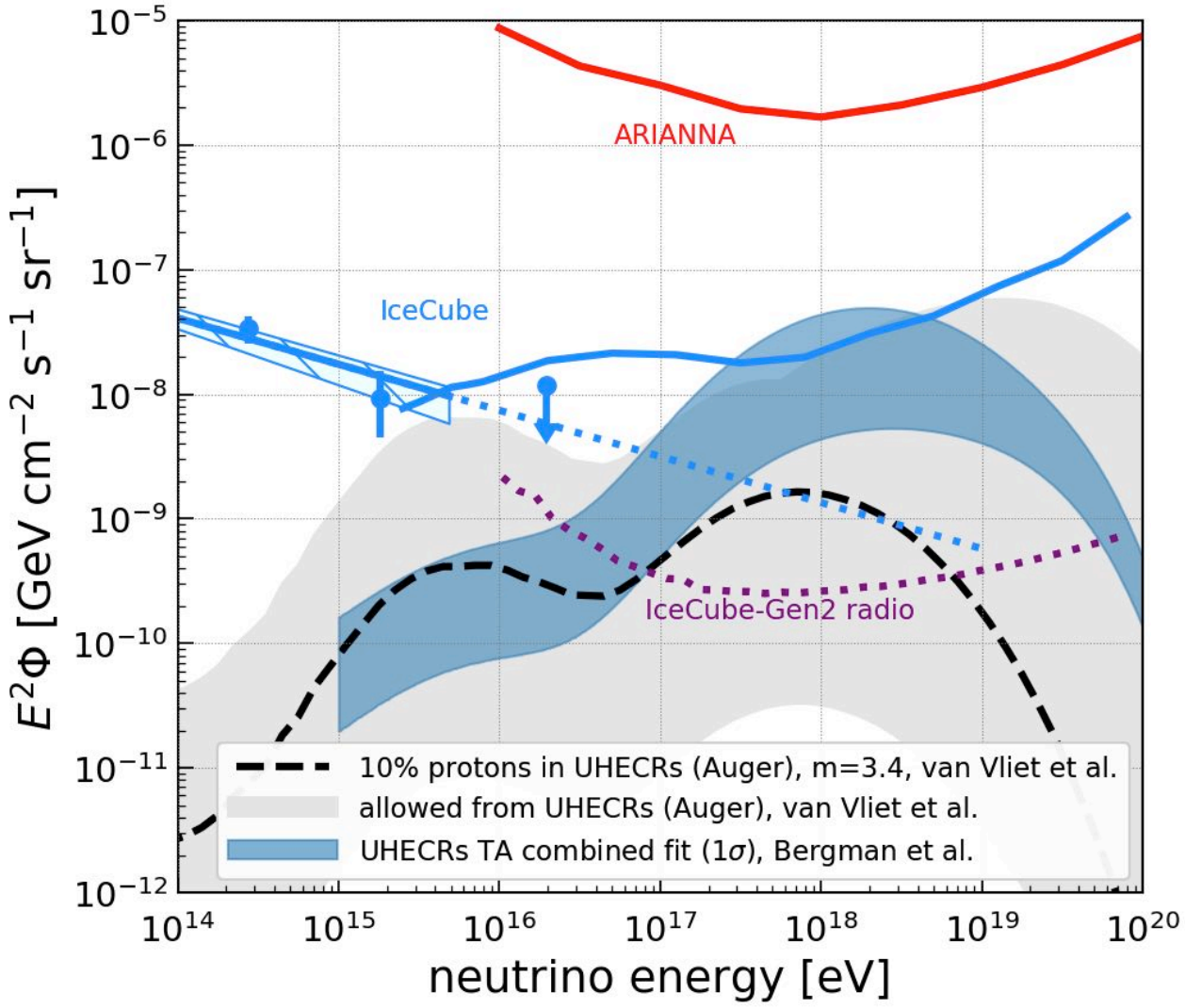
Development of wind power system

- 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

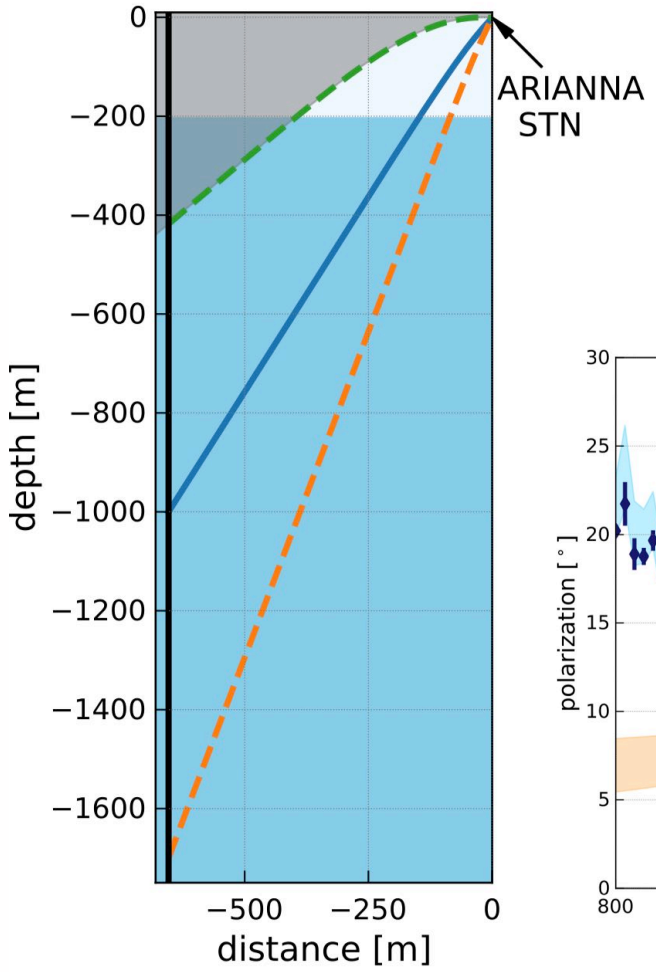


Neutrino Search

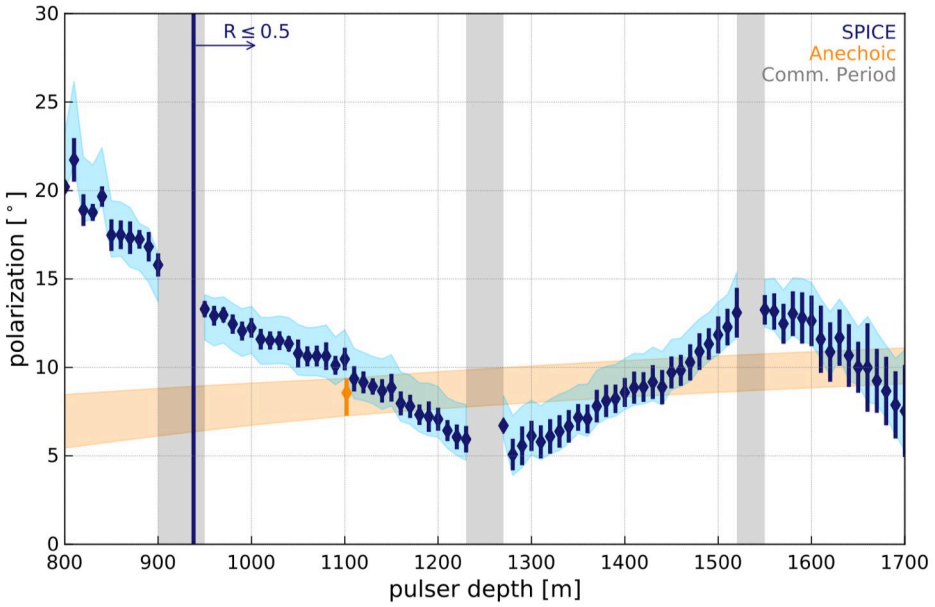
- Analysis of 4.5 years of data of ARIANNA test-bed array
- No neutrino found
- Demonstrates feasibility of radio technology



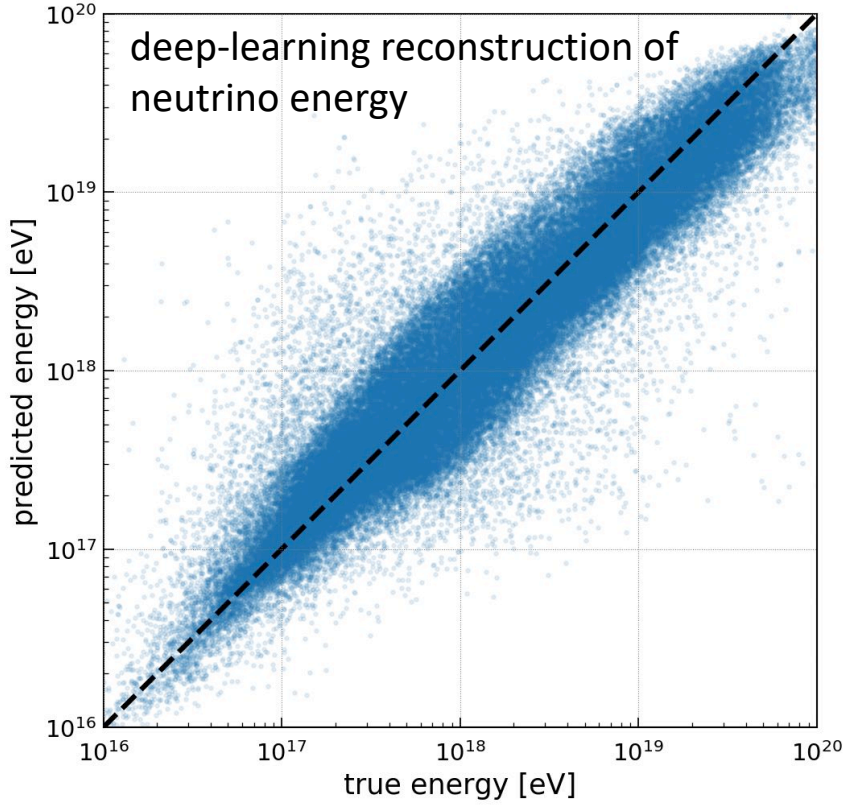
Event Reconstruction



In-situ test of angular and polarization reconstruction

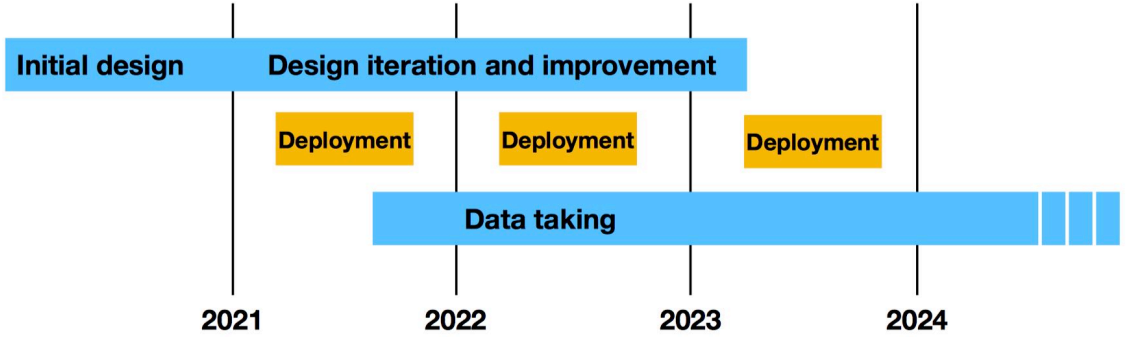


- software development
- simulation (NuRadioMC) and reconstruction (NuRadioReco)
- open-source on github

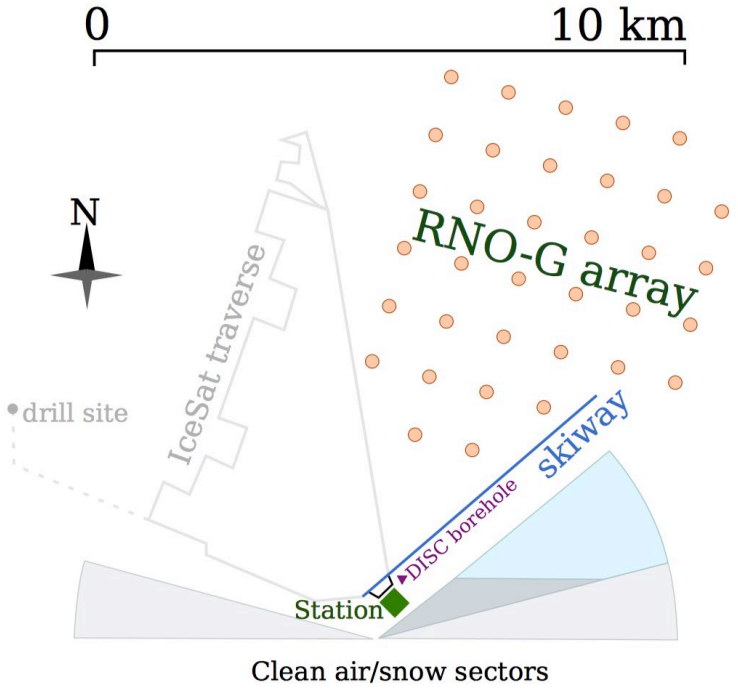


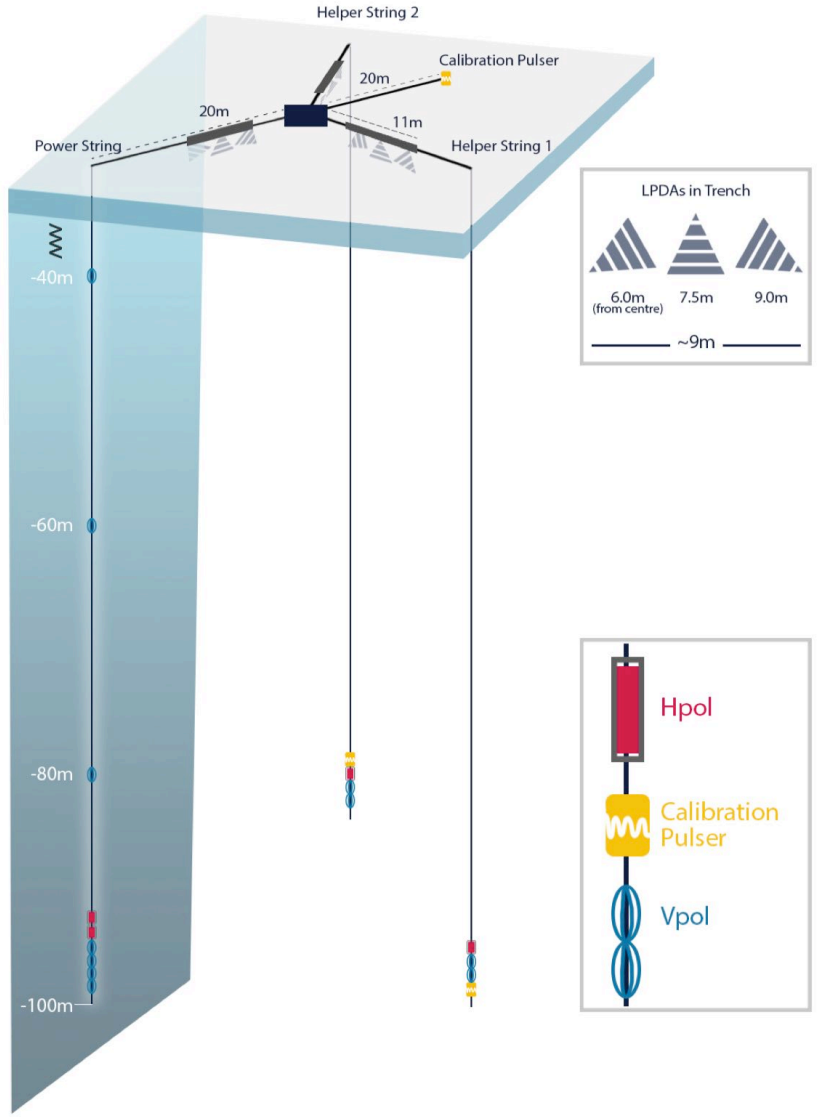
The future part I: RNO-G (Radio Neutrino Observatory – Greenland)

RNO-G collaboration, arXiv:2010.12279



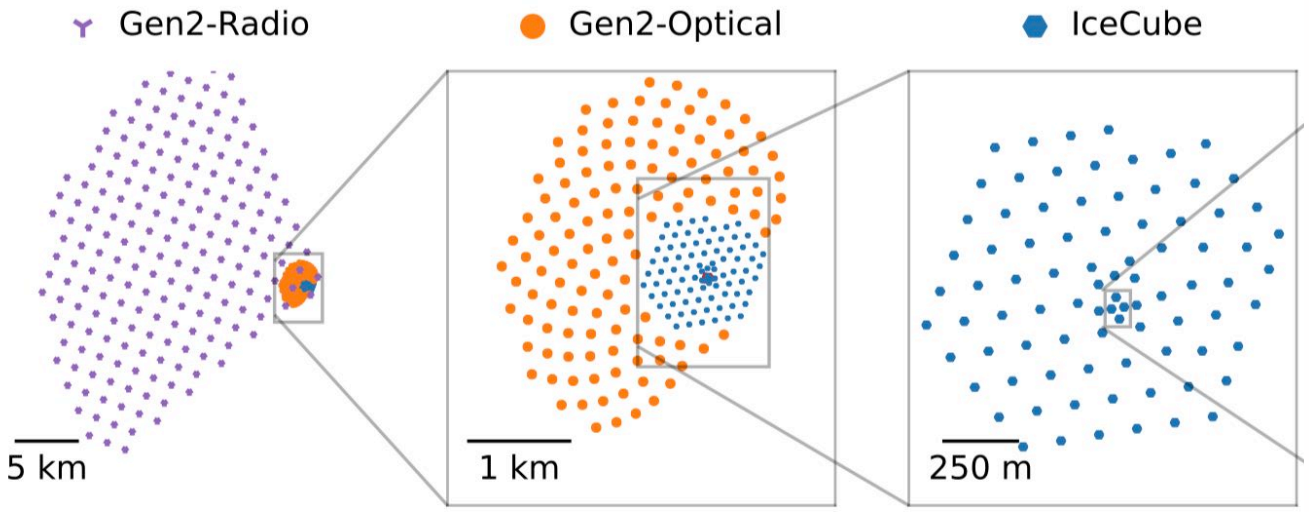
- 35 autonomous stations
- Uppsala contributes wind power system

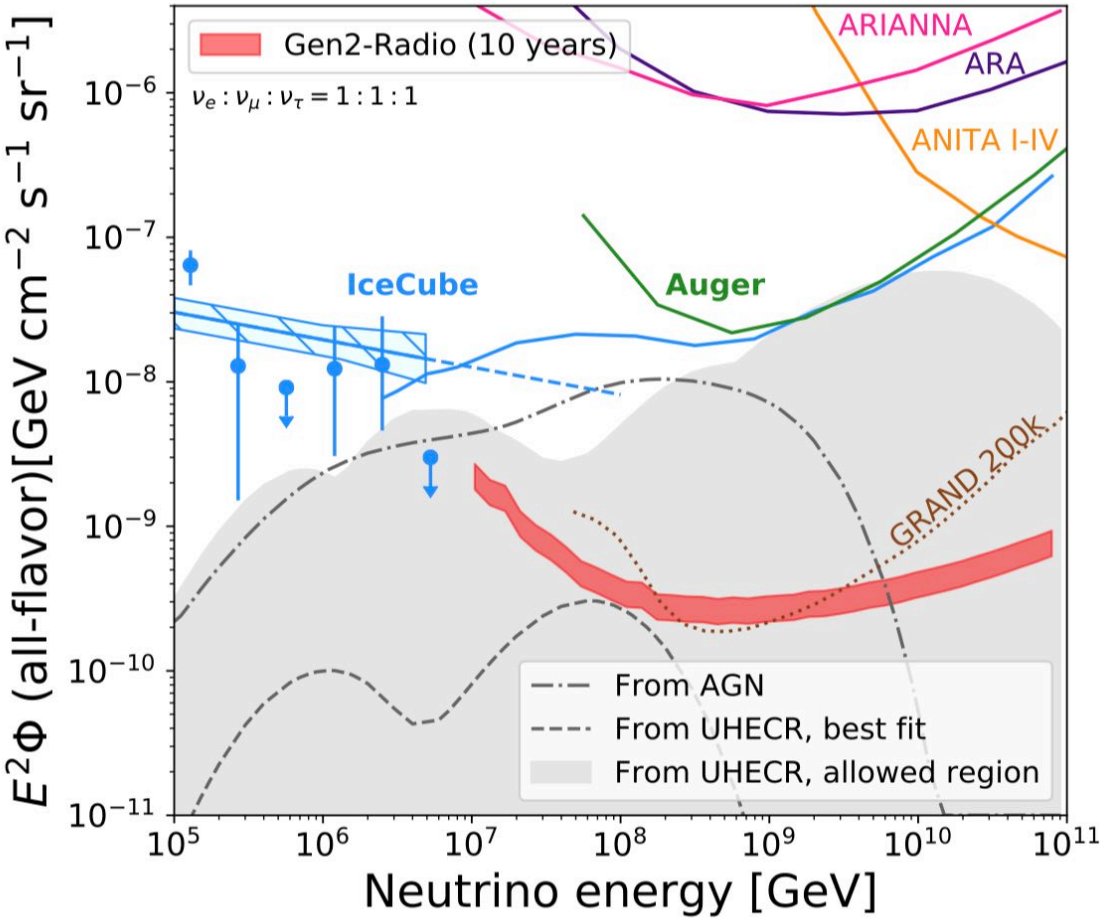




The future part II: IceCube-Gen2

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





Summary

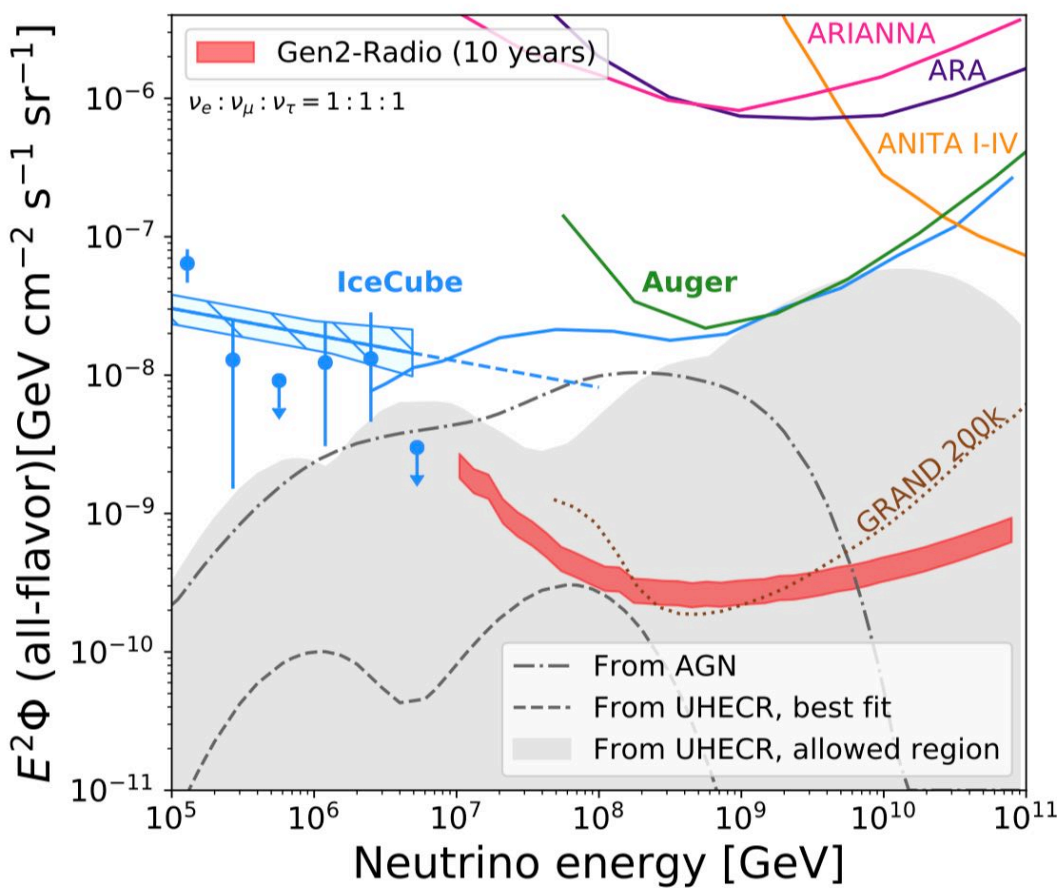
- Radio detection is an intriguing (new) technique to detect neutrinos of the highest energies
- Emission properties well understood
- Technology proven in pilot arrays

- Future:
  - RNO-G: 35 stations in Greenland
  - Radio component of IceCube-Gen2: 200+ stations at the South Pole

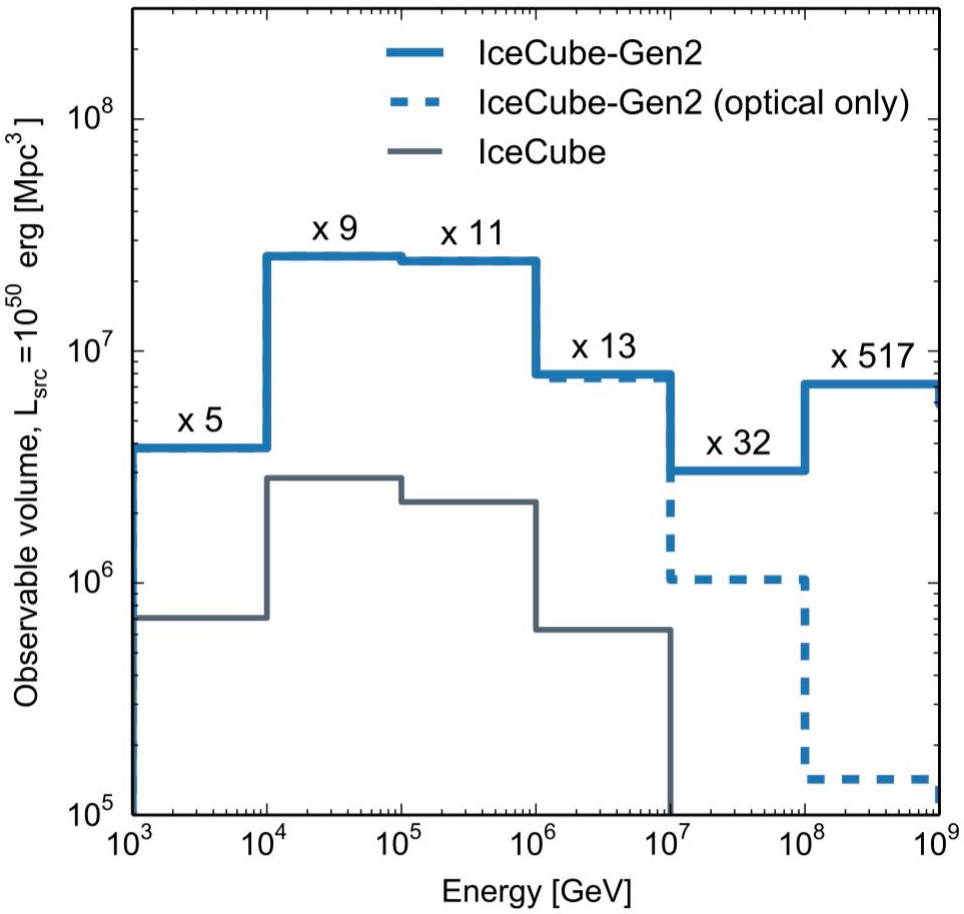
backup

Science Potential IceCube-Gen2 Radio

Diffuse neutrino flux



Explosive sources



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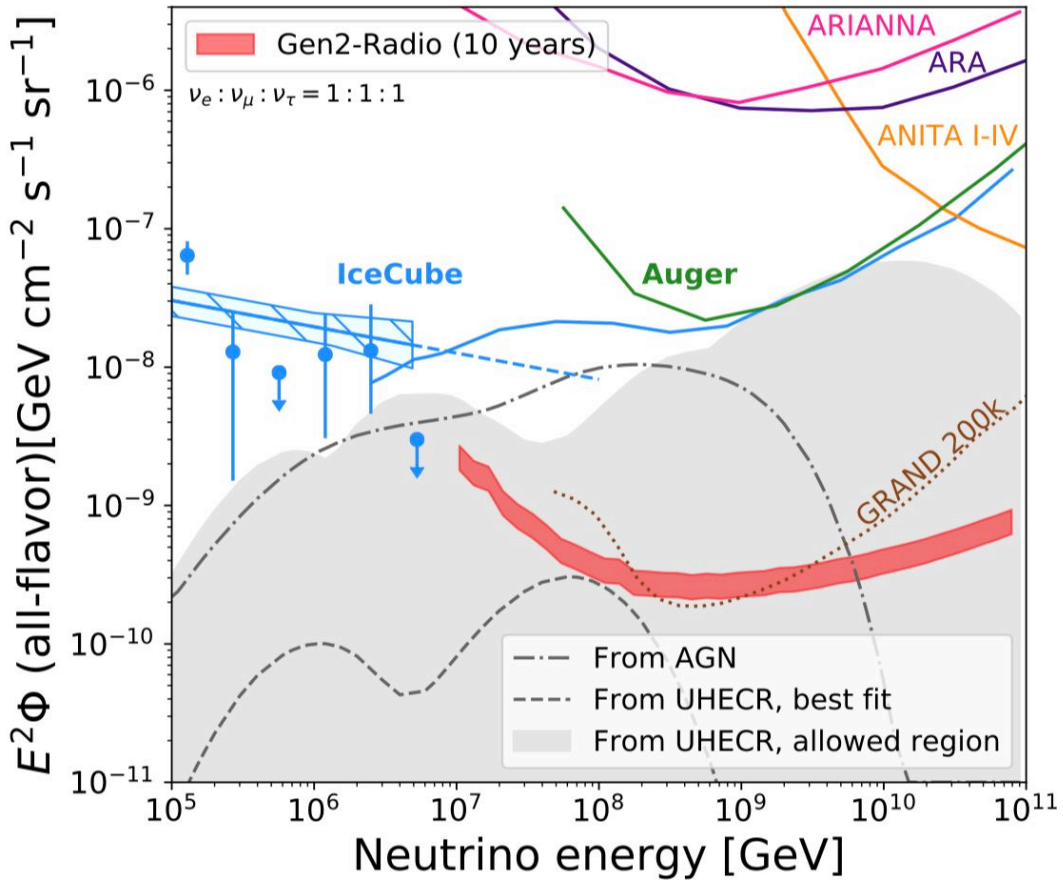
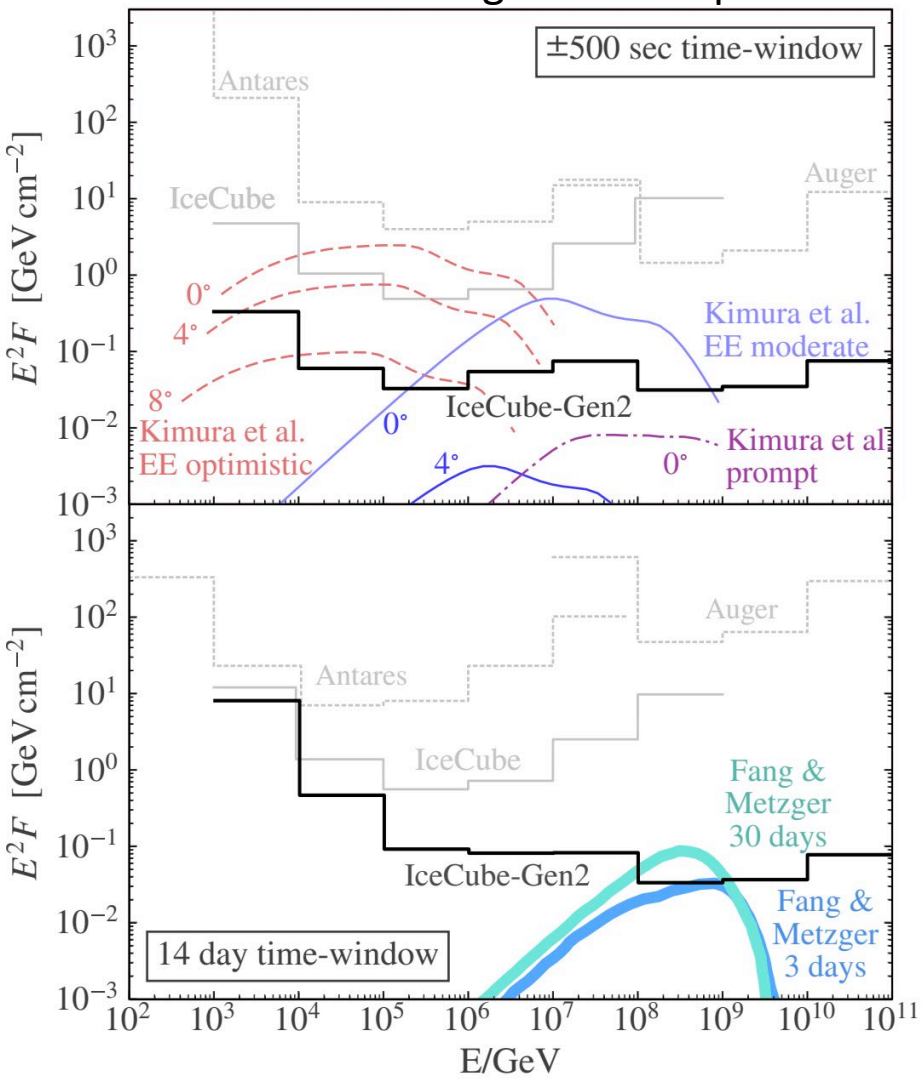


Explosive sources

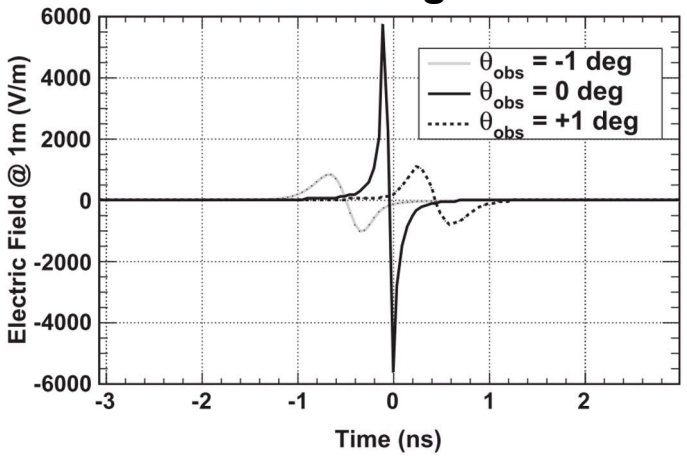
NS-NS merger follow up



ARIANNA collaboration, JCAP 03(2020)053

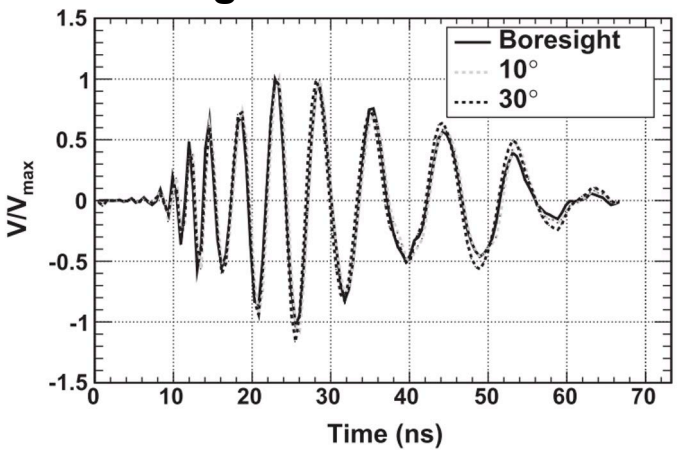
Example: ARIANNA neutrino search

neutrino signal



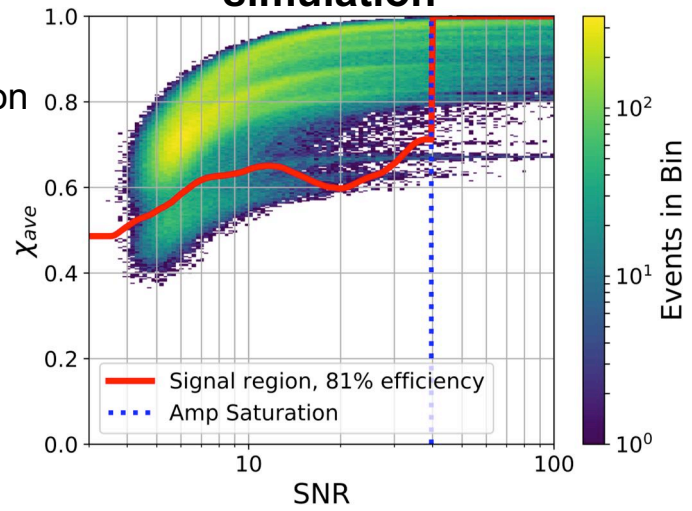
hardware response

signal in detector

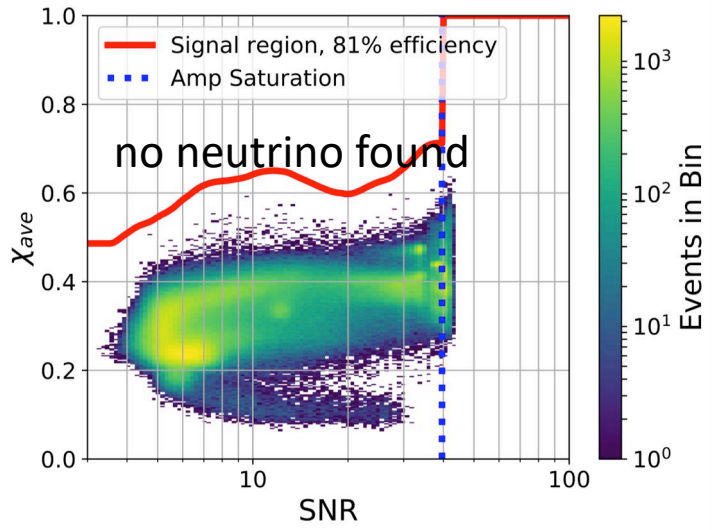


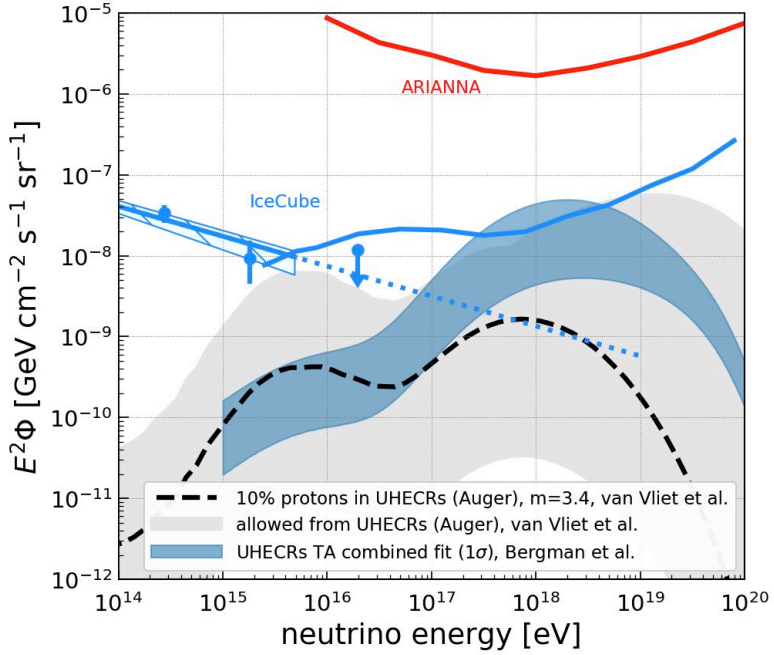
template correlation

simulation



data





better use Neutrinos instead of cosmic rays

- Cosmic rays gets accelerated up to 10^{20}eV
- Cosmic rays produce neutrinos (at the source + GZK: CR+CMB)
- **Neutrinos: Excellent messenger particle**
  - Electrically neutral, (almost) no mass, small interaction cross section
- Coincident detection with EM and gravitational waves (**multi messenger**)