Radio neutrino telescopes: Status and perspectives

Anna Nelles

XVIII International Workshop on Neutrino Telescopes, Venice, 2019

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

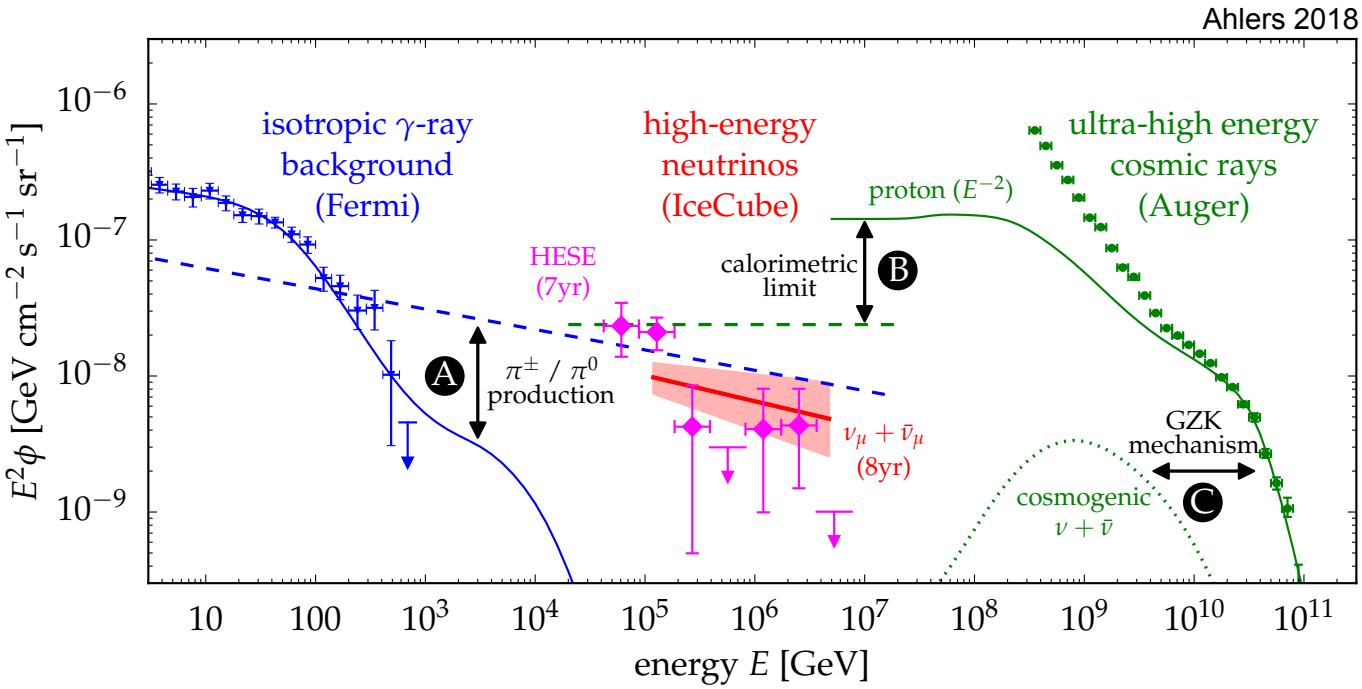
Emmy Noether-Programm
DFG Deutsche Forschungsgemeinschaft

NE 2030/2-1

DESY.

Astrophysical and cosmogenic neutrinos

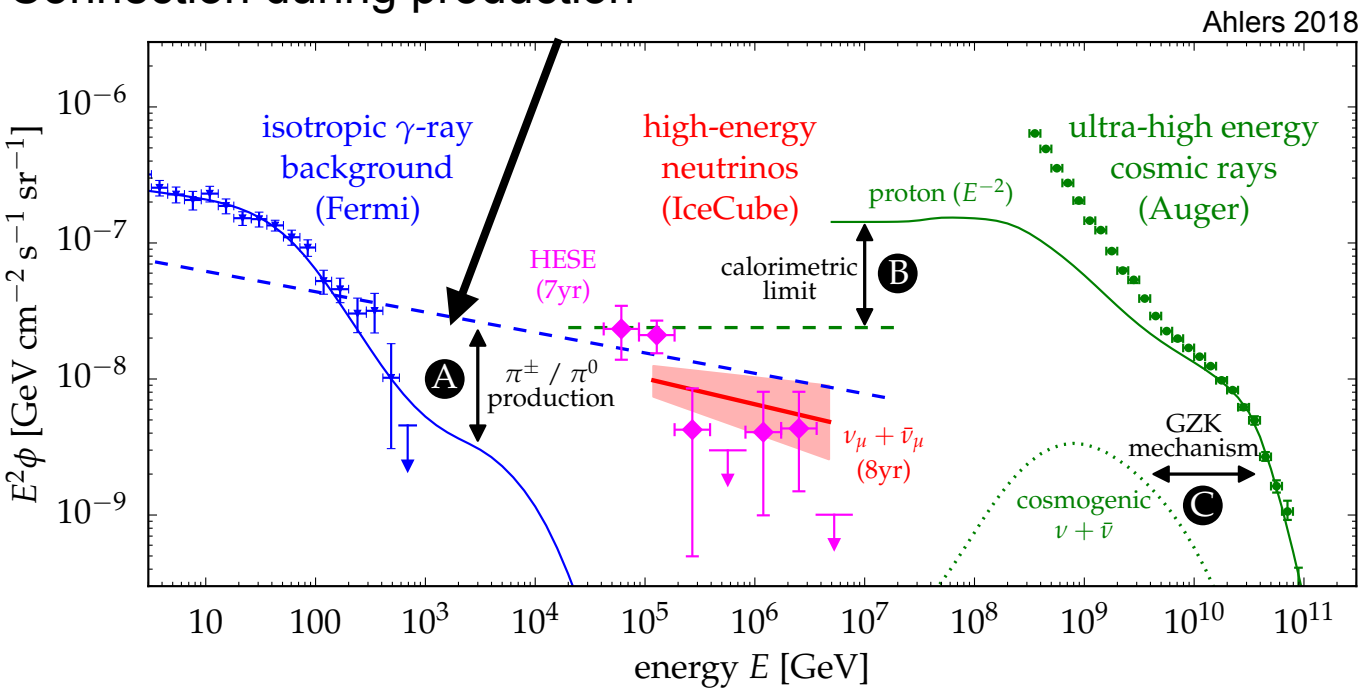
What kind of neutrinos are we hunting for?



Astrophysical and cosmogenic neutrinos

What kind of neutrinos are we hunting for?

Connection during production

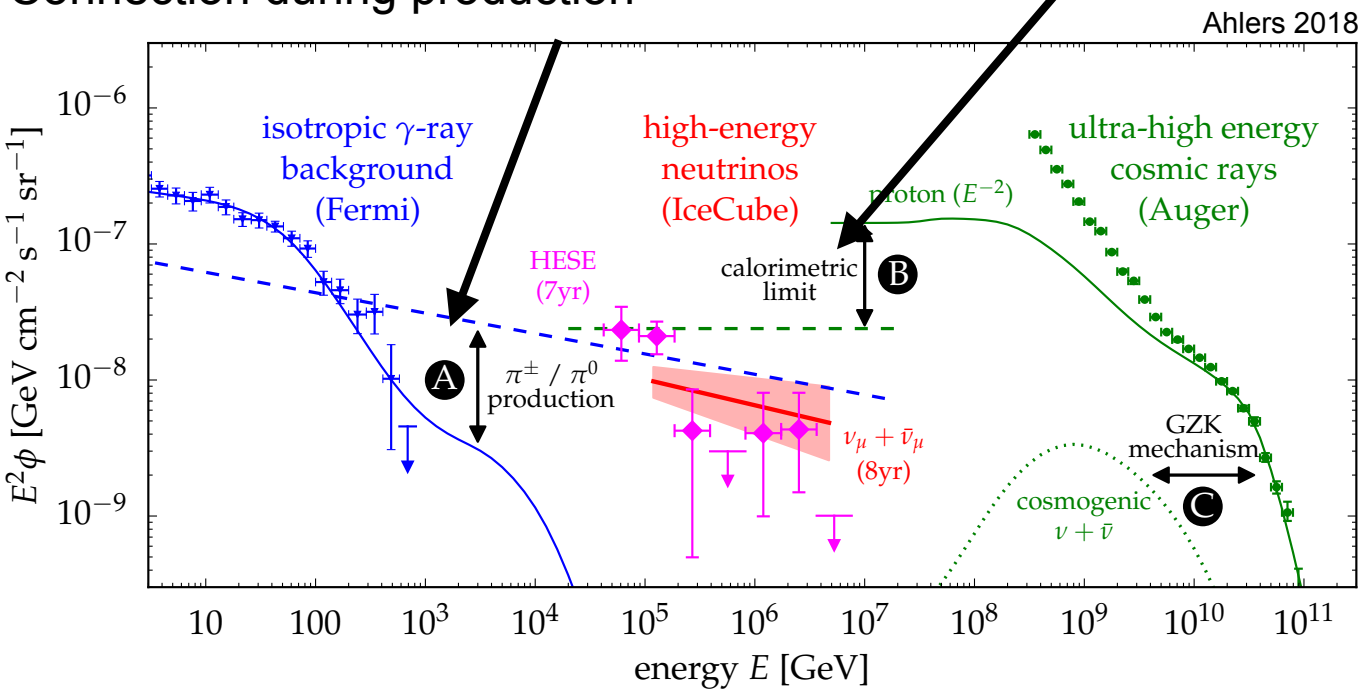


Astrophysical and cosmogenic neutrinos

What kind of neutrinos are we hunting for?

There cannot be more energy in neutrinos than in cosmic rays, if they are produced together

Connection during production

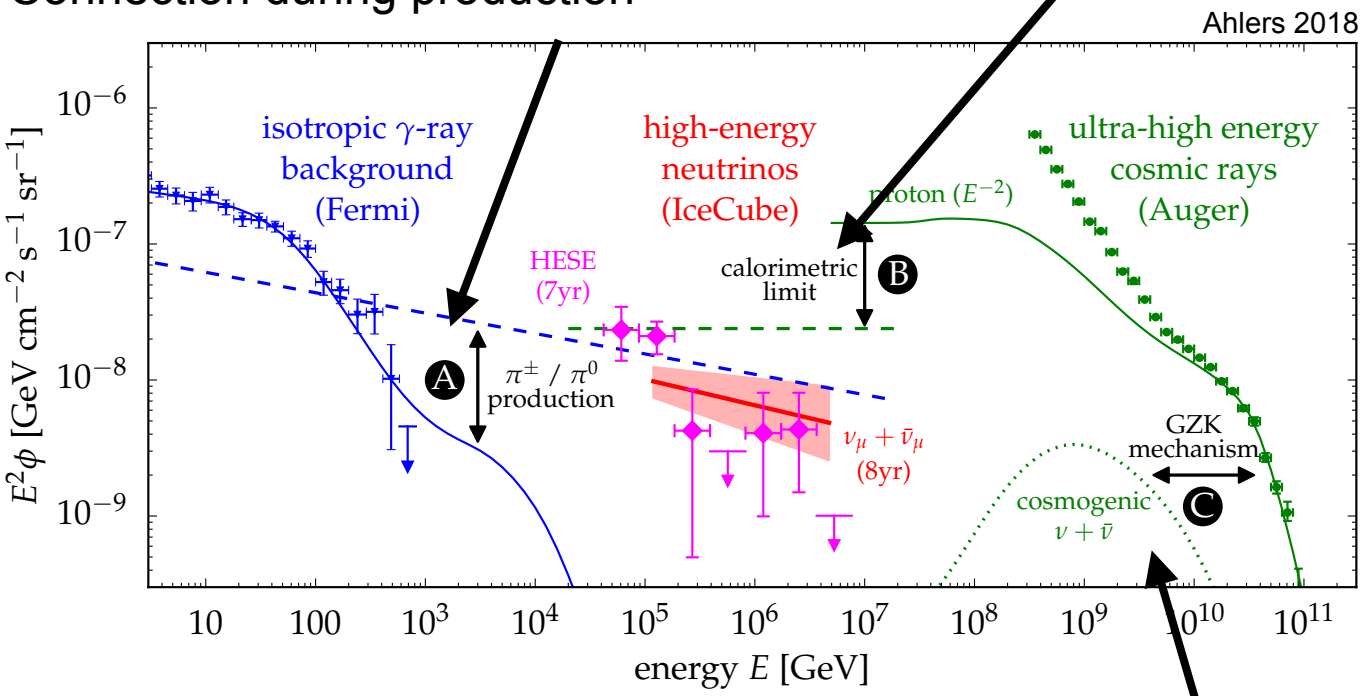


Astrophysical and cosmogenic neutrinos

What kind of neutrinos are we hunting for?

There cannot be more energy in neutrinos than in cosmic rays, if they are produced together

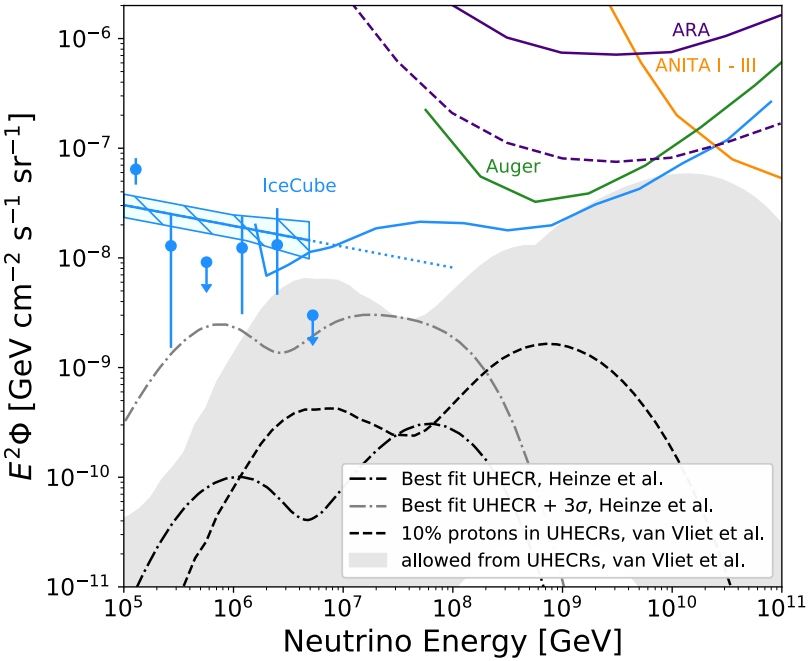
Connection during production



Cosmic-rays interact with CMB and IR background

Radio detection of neutrinos

Why radio?



If you want a 'real' shot at cosmogenic neutrinos:

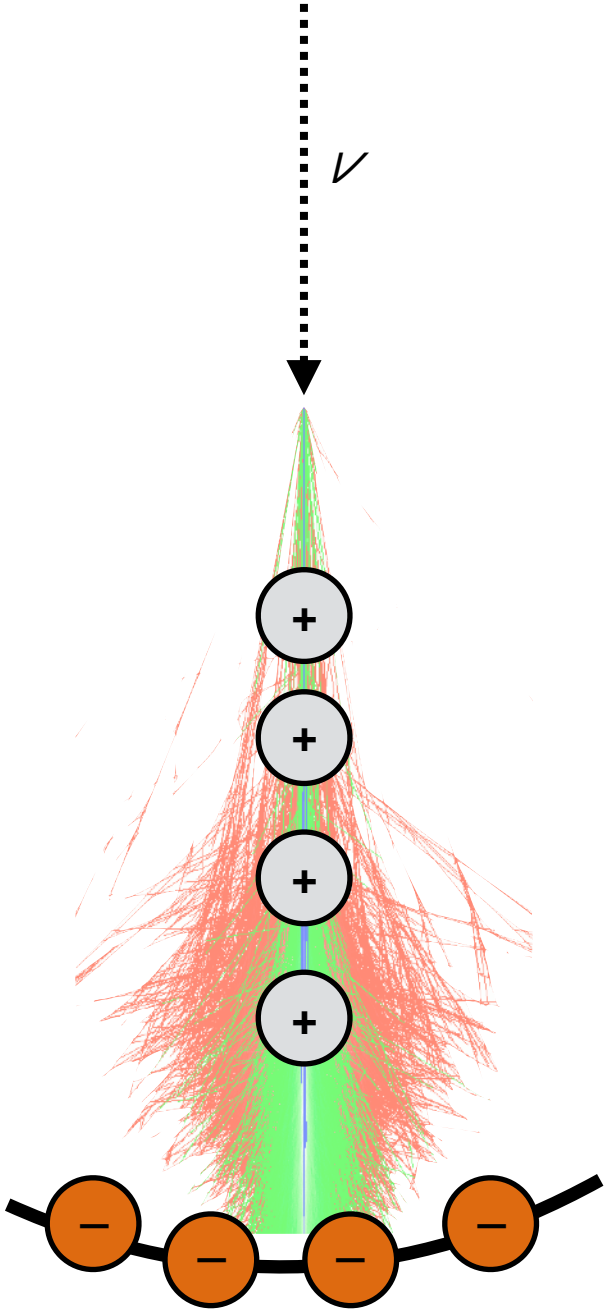
- Build a detector of 100x the size of IceCube
- At 100 km^3 better use a detection medium that is free = air, water, ice
- Using optical technologies: financially not feasible
  - air not dense enough for neutrinos
  - water and ice: attenuation length to small
- Come up with a different technology:
  - Radio Detection in Ice

Radio Detection of Neutrinos

In a (very small) nutshell

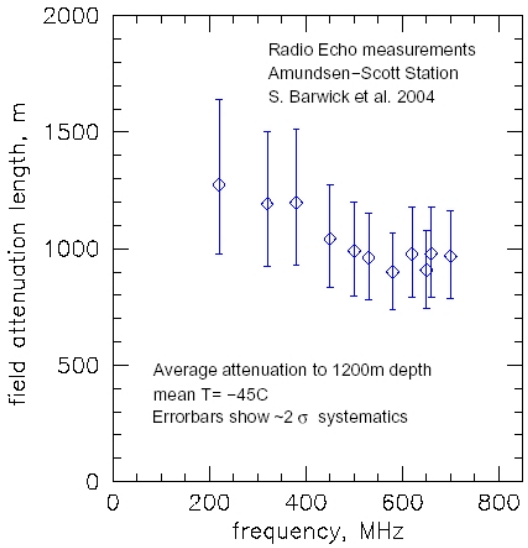
Neutrino interaction creates hadronic or electro-magnetic shower:

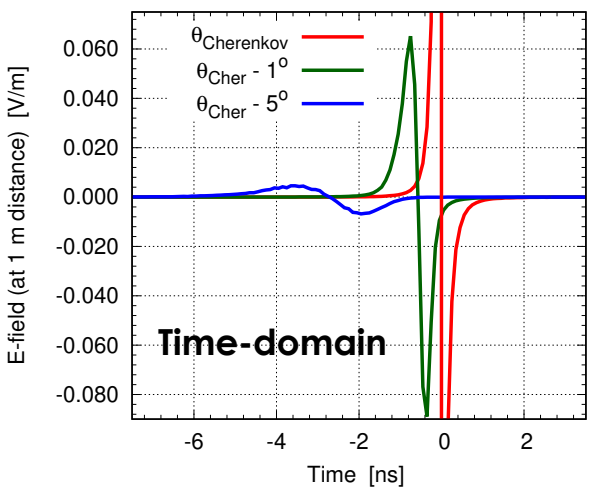
- Shower develops in dense medium
- Shower front becomes increasingly negative (Compton effect on electrons in medium)
- Macroscopically (i.e. at long wavelengths) this looks like a moving charge/dipole
- Total charge increases and decreases with shower development
- A moving charge creates emission, it is coherent (i.e. strong) at radio wavelengths

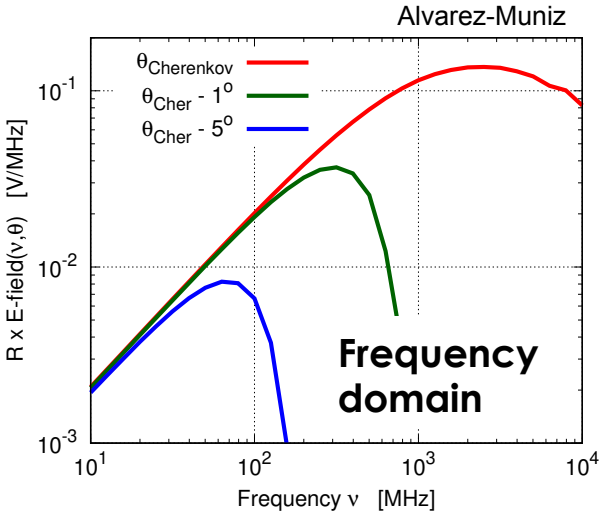


Radio Detection in Ice

Boundary conditions



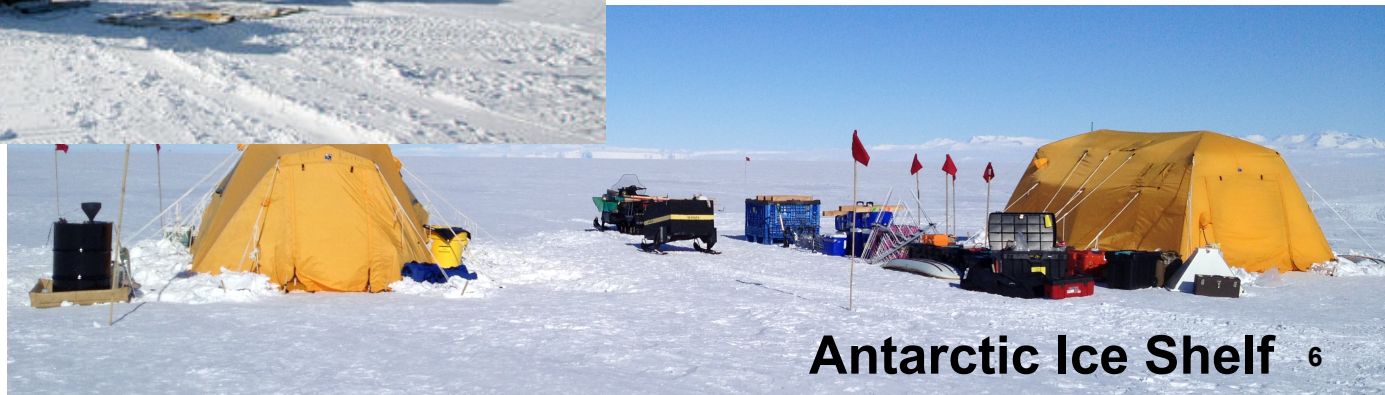




- Attenuation length in polar ice is about 1 km:
  - very good for sparse instrumentation
- Detection threshold is roughly 1 PeV
  (for non-cooled electronics above the Galactic synchrotron background):
  - high in comparison to optical, but spot-on for cosmogenic neutrinos
- We are looking for single pulses at 10 MHz - 1 GHz

Pilot-arrays

Different experimental strategies

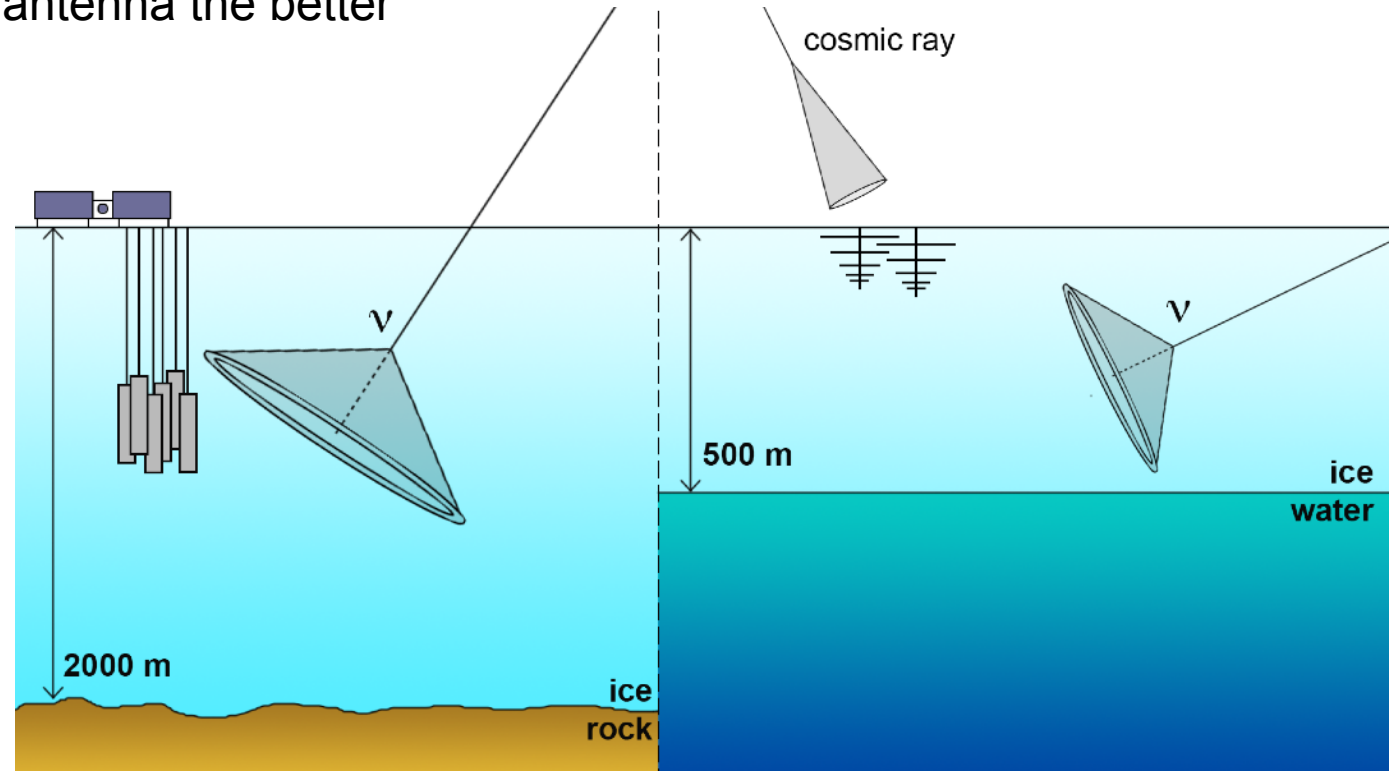


Experimental approaches

Don’t ever believe a theorist calling things “easy to measure”

As many sensitive antennas as possible need to be distributed in the ice

- The deeper the better the attenuation length of the ice
- The deeper the more expensive the drilling and cabling
- The bigger the antenna the better
- …

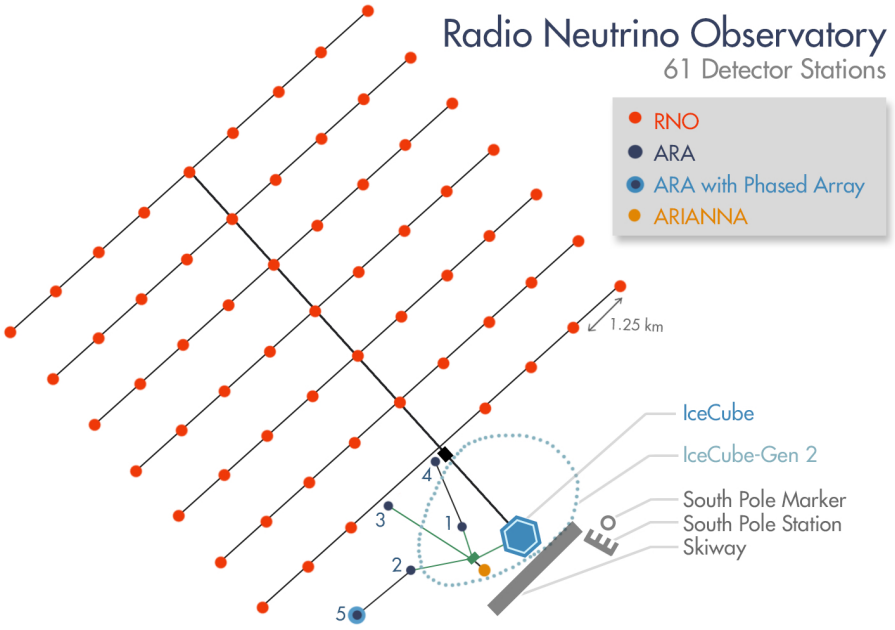


The Future

Radio Neutrino Observatory

Proposal for mid-scale funding at NSF, Radio Neutrino Observatory: RNO

- will be the first experiment with serious sensitivity
- will detect the continuation of the ‘famous’ IceCube flux, if not cut-off at 10 PeV
- will detect cosmogenic neutrinos, if 10% of the are protons at the highest energies
- will teach us the best strategy to reconstruct arrival directions and energies in real conditions, stations are “over-instrumented” since first radio detection of a neutrino

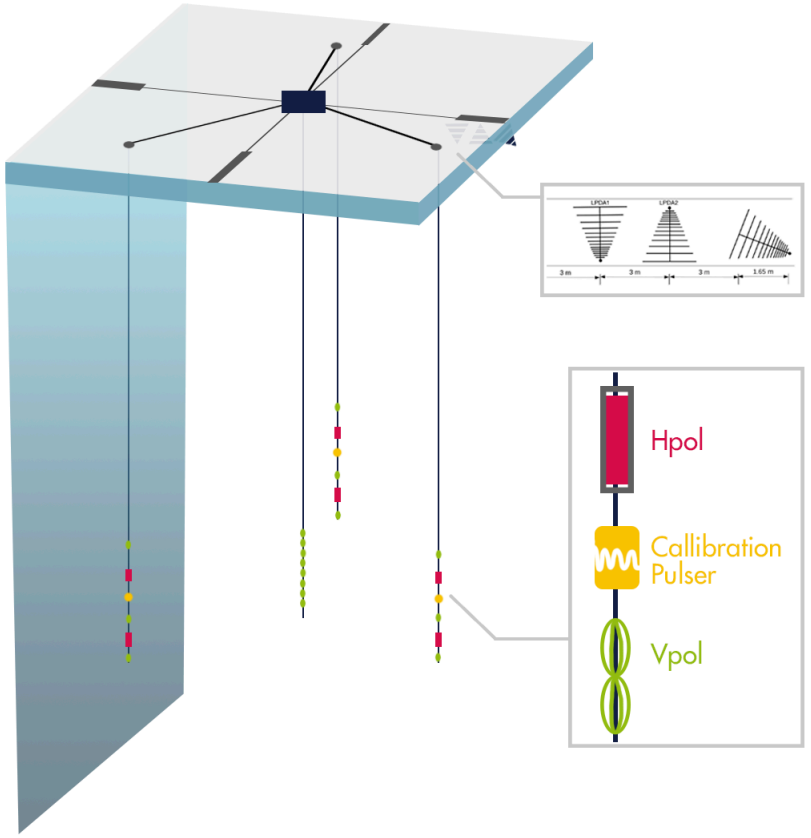


The Future

Radio Neutrino Observatory

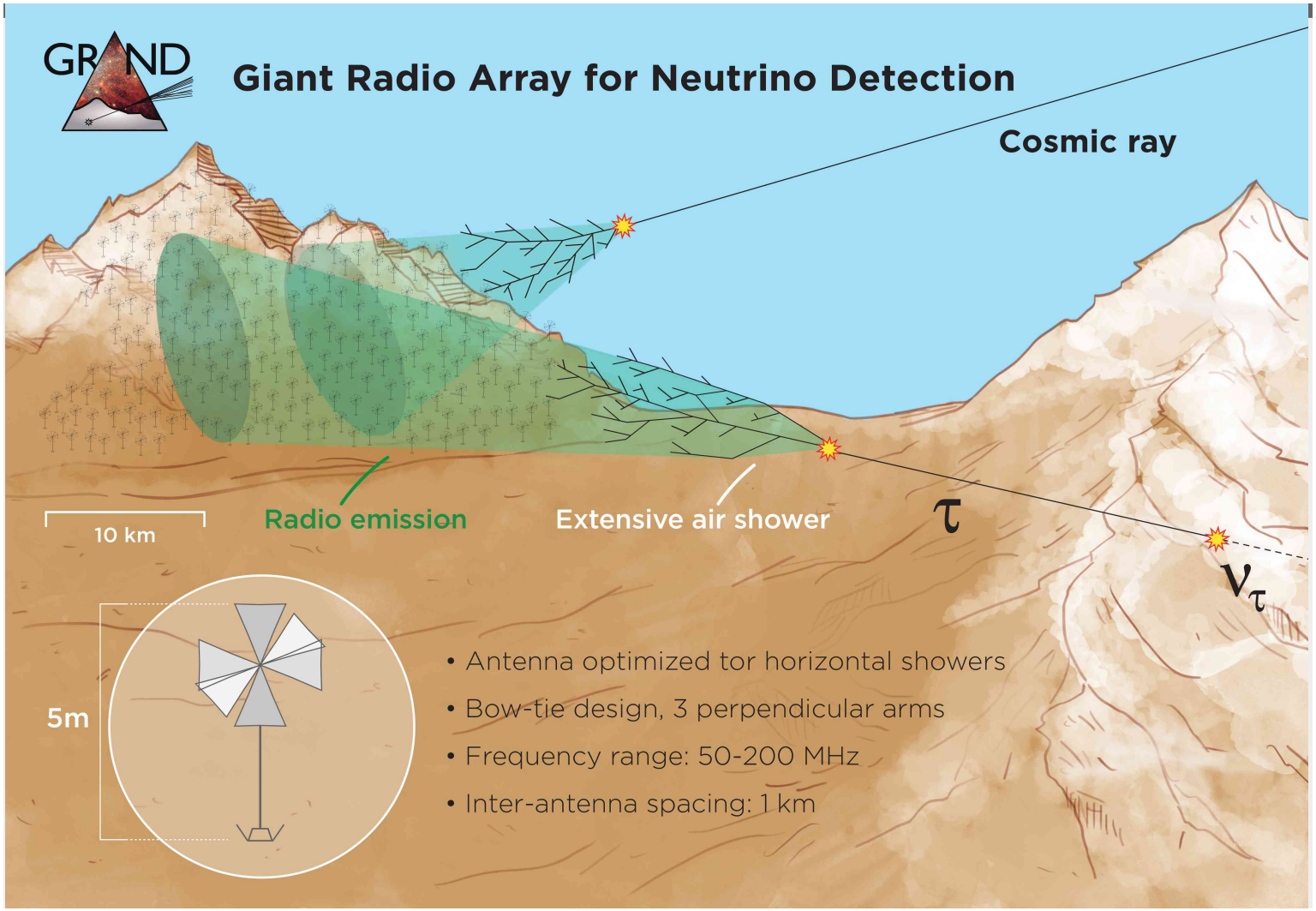
Proposal for mid-scale funding at NSF, Radio Neutrino Observatory: RNO

- will be the first experiment with serious sensitivity
- will detect the continuation of the ‘famous’ IceCube flux, if not cut-off at 10 PeV
- will detect cosmogenic neutrinos, if 10% of the are protons at the highest energies
- will teach us the best strategy to reconstruct arrival directions and energies in real conditions, stations are “over-instrumented” since first radio detection of a neutrino



The Future

GRAND



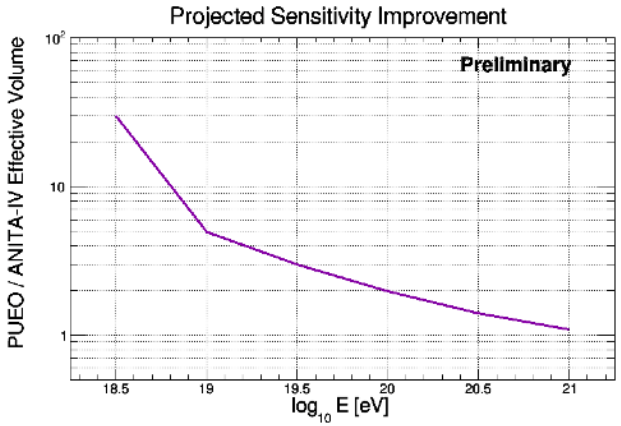
Credit: GRAND Collaboration

The Future

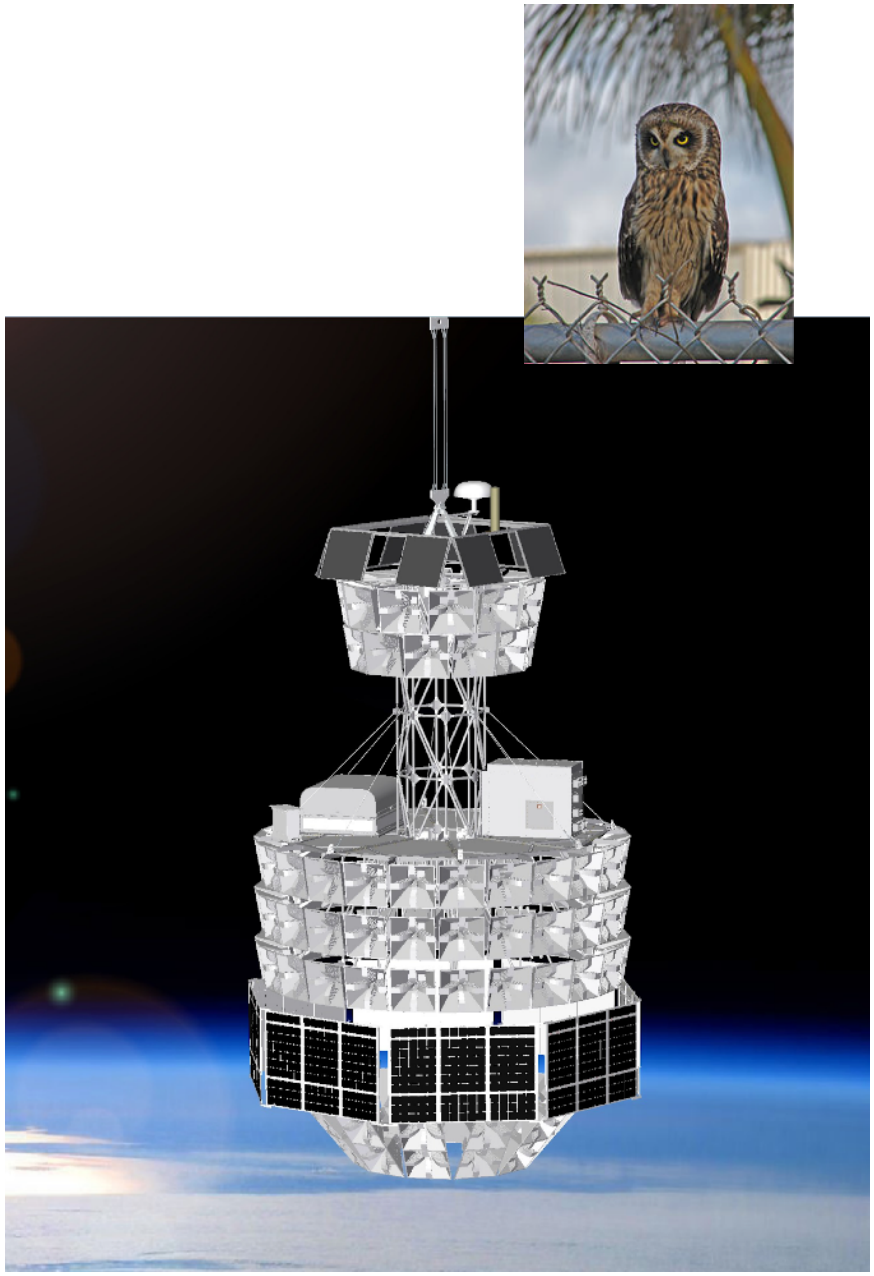
Next-generation balloon: PUEO

Proposal pending: "Payload for Ultrahigh Energy Observations"

- 2.5x lower threshold than ANITA-IV
  - More antennas (120 vs. 48), but higher-frequency (300 MHz vs. 200 MHz cutoff)
  - 16-antennas phased together at a time using a low-bit streaming digitizer as trigger



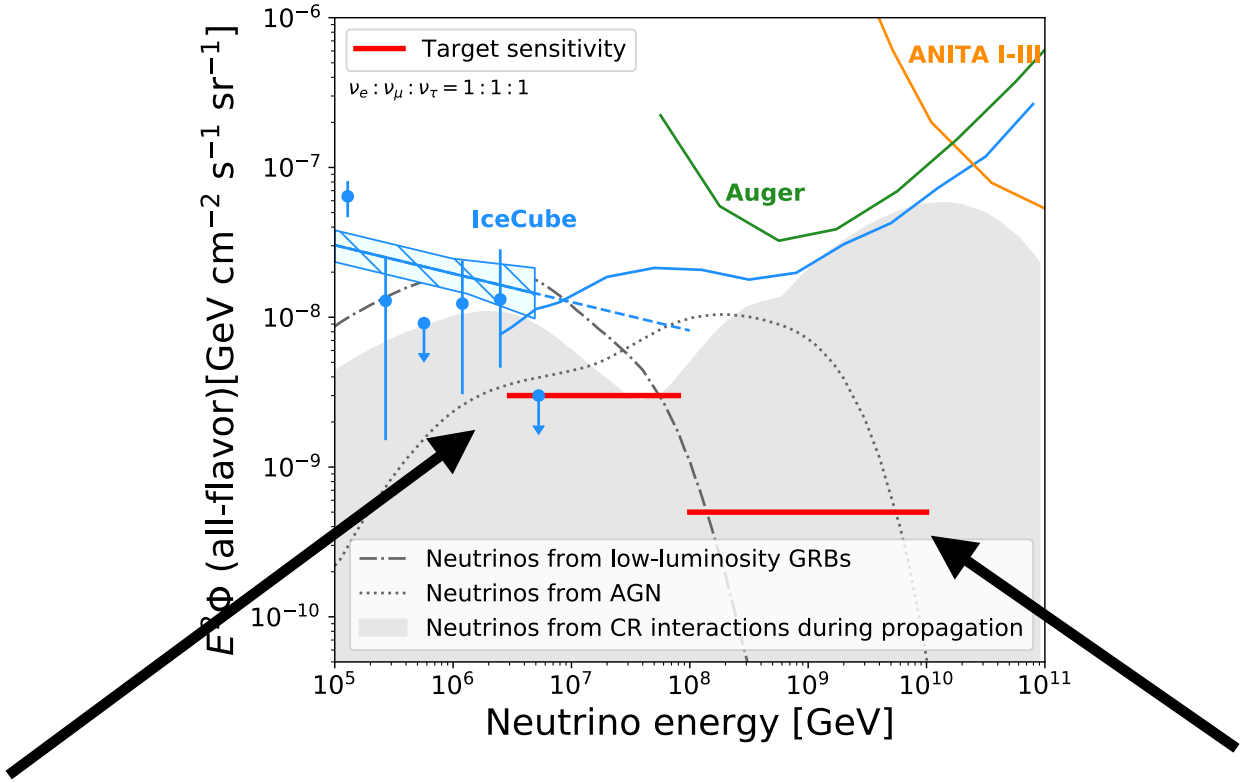
- 24 antennas in inclined array for steep "mystery events"



Credit: Cosmin Deaconu

The Future

Where do we need to aim?

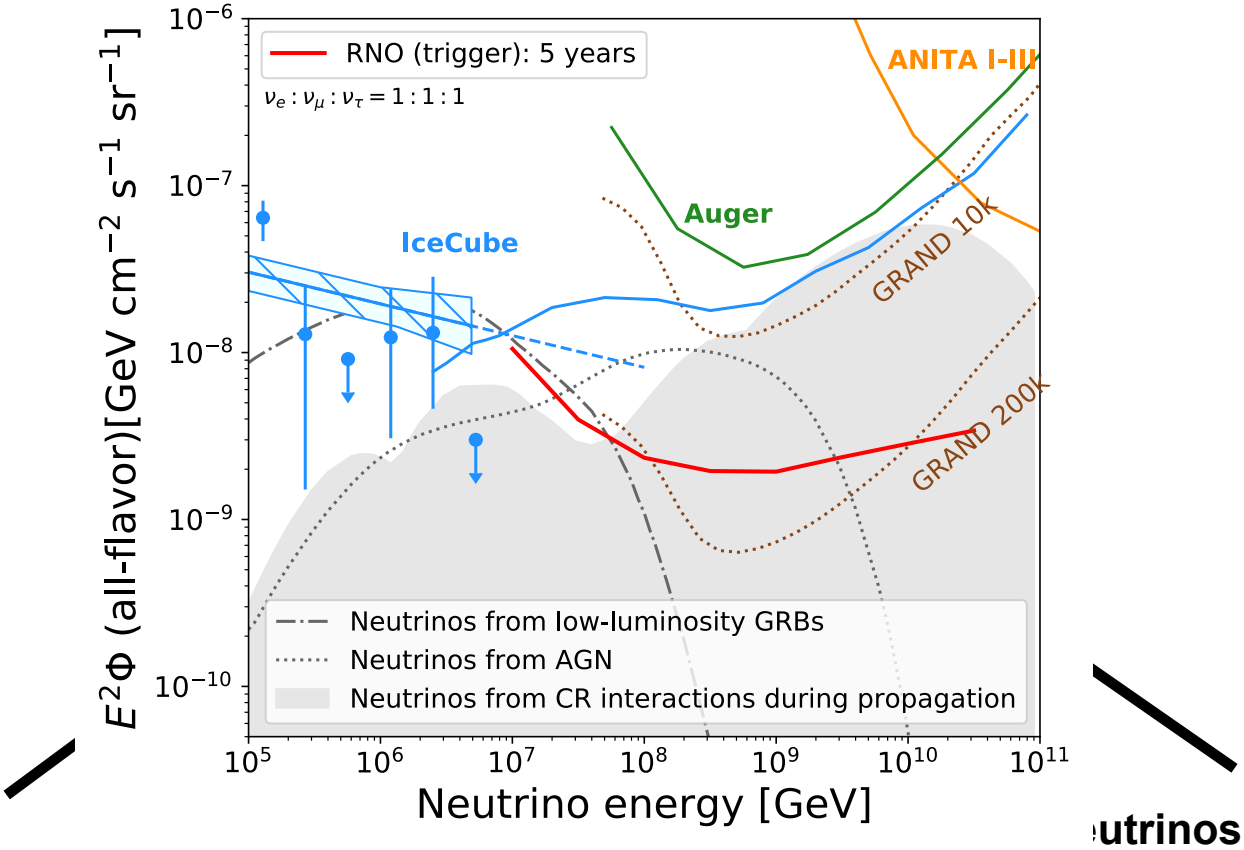


Continuation of IceCube Flux
radio has a natural threshold at ~1 PeV, push as low as possible

"GZK" neutrinos
fits to CR composition, prefer very low fluxes, push as sensitive as possible

The Future

Where do we need to aim?

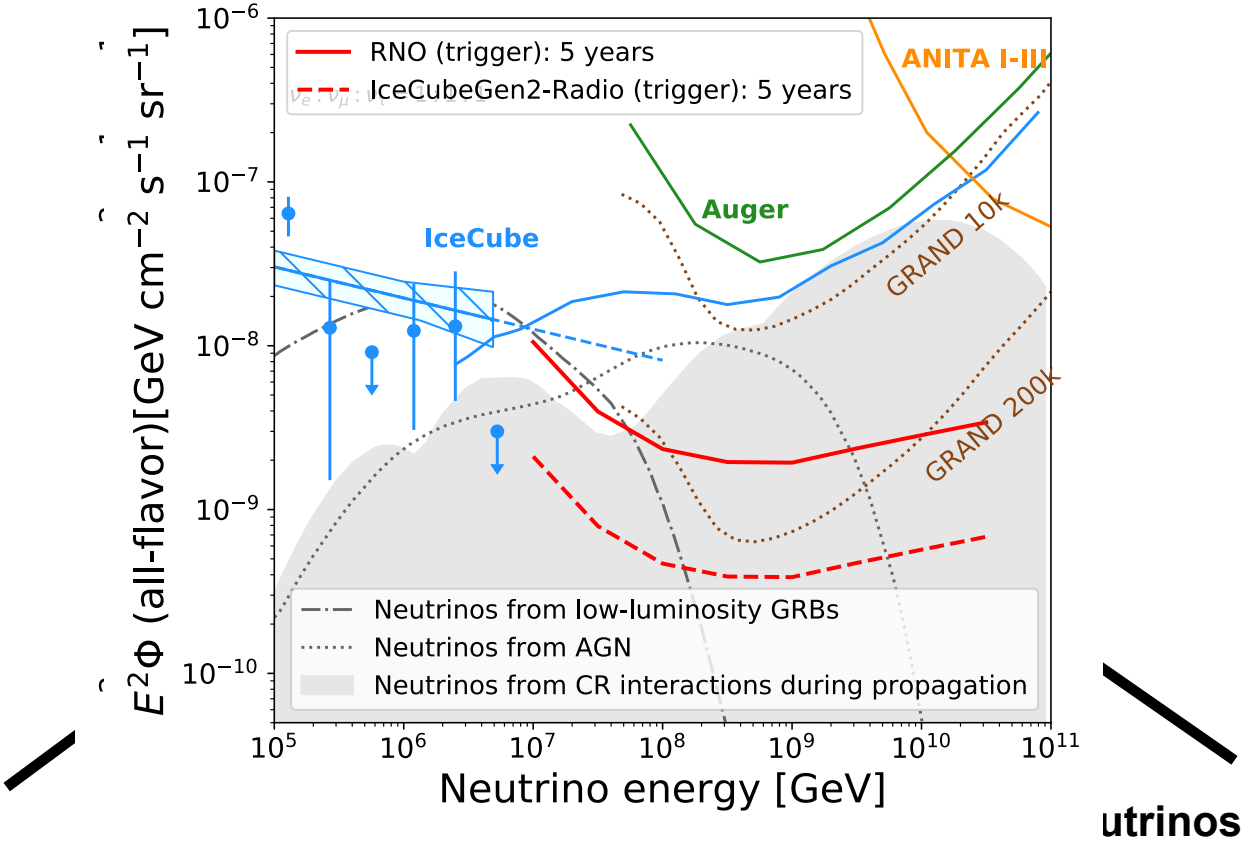


Continuation of IceCube Flux
radio has a natural threshold at ~1 PeV, push as low as possible

utrinos
fits to CR composition, prefer very low fluxes, push as sensitive as possible

The Future

Where do we need to aim?



Continuation of IceCube Flux
radio has a natural threshold at ~1 PeV, push as low as possible

utrinos
fits to CR composition, prefer very low fluxes, push as sensitive as possible

Track-record

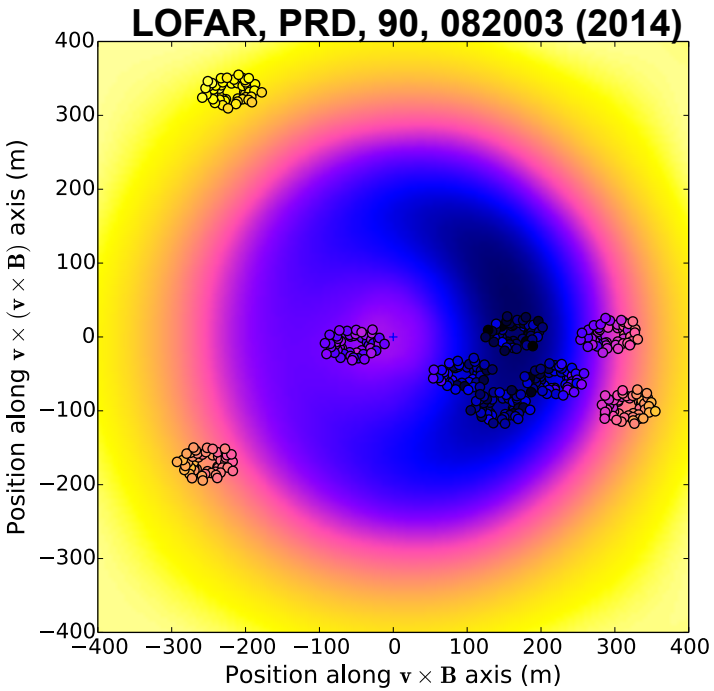
Why are we confident that this is a good plan?

- Radio detection of showers experimentally verified in air with cosmic rays:
  > 30 peer-reviewed publications,
  radio detection of air showers has advanced to standard-technique

Track-record

Why are we confident that this is a good plan?

- Radio detection of showers experimentally verified in air with cosmic rays:
  > 30 peer-reviewed publications,
  radio detection of air showers has advanced to standard-technique

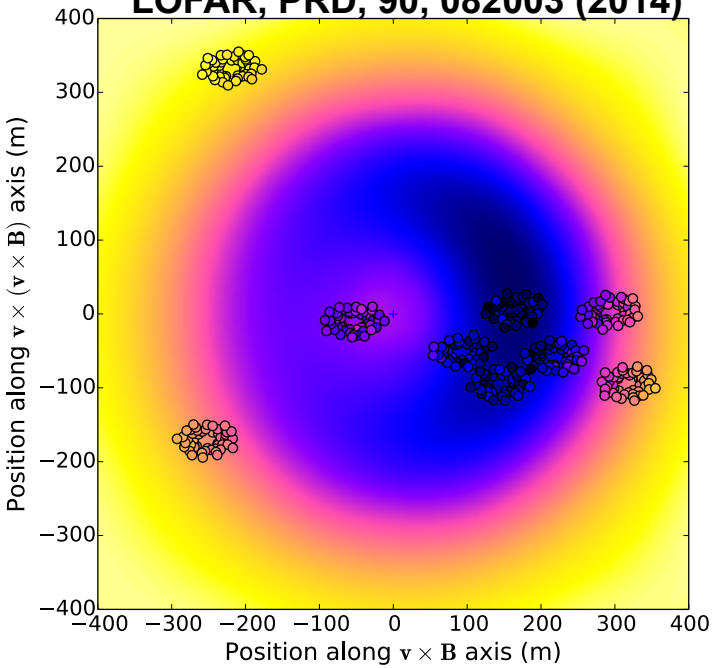


Track-record

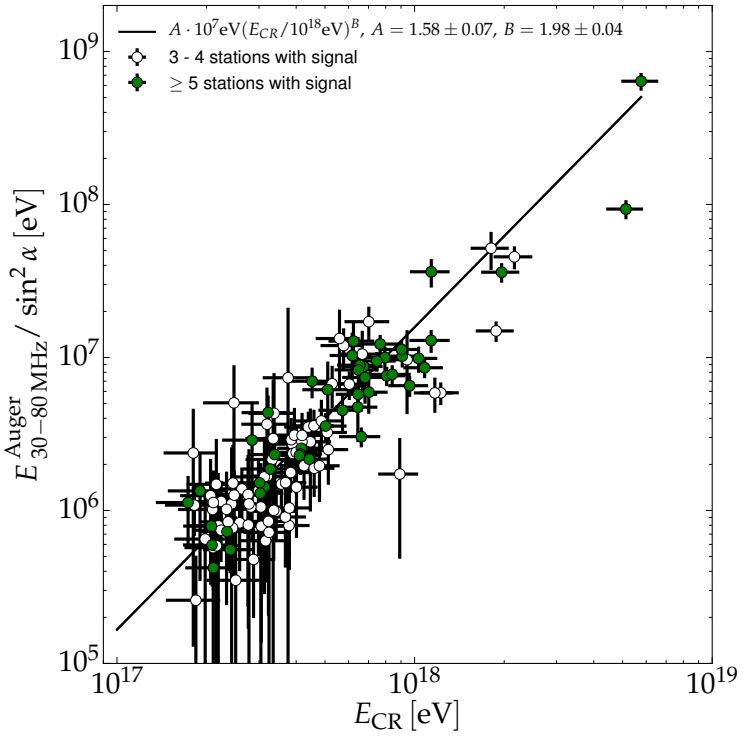
Why are we confident that this is a good plan?

- Radio detection of showers experimentally verified in air with cosmic rays:
  > 30 peer-reviewed publications,
  radio detection of air showers has advanced to standard-technique

LOFAR, PRD, 90, 082003 (2014)



Auger Coll., PRL 116, 241101 (2016)



Track-record

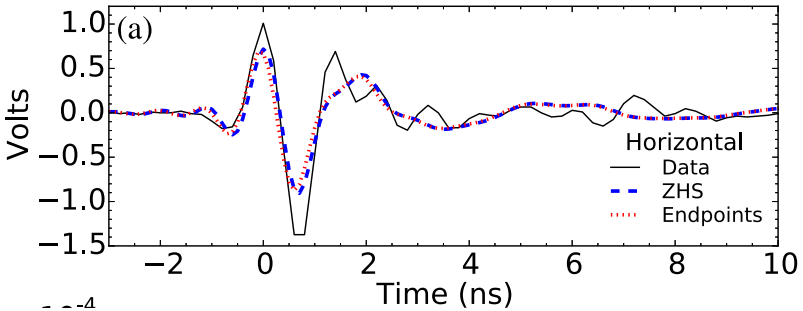
Why are we confident that this is a good plan?

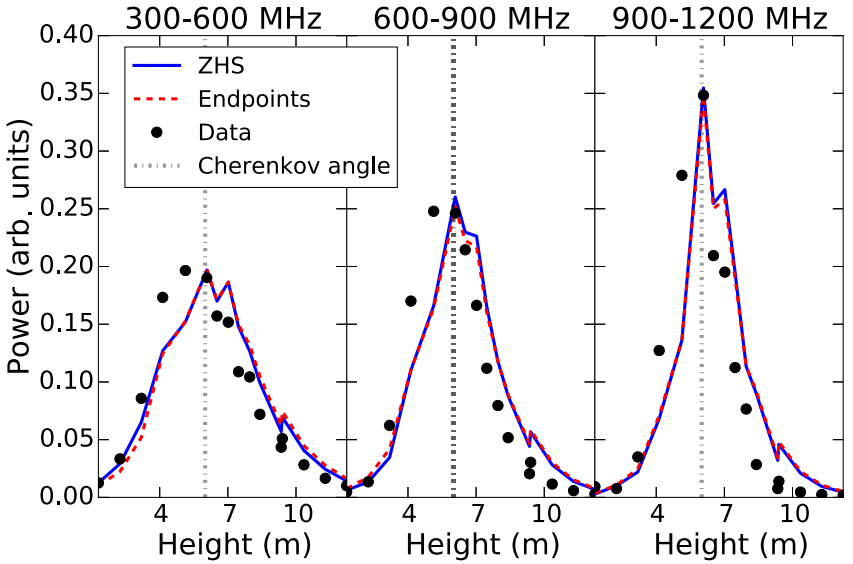
- Radio detection of showers experimentally verified in air with cosmic rays:
  > 30 peer-reviewed publications,
  radio detection of air showers has advanced to standard-technique
- Theoretical emission modeling solid:
  verified at SLAC accelerator,
  3 independent theoretical descriptions agree to < 10% in amplitude

Track-record

Why are we confident that this is a good plan?

- Radio detection of showers experimentally verified in air with cosmic rays:
  > 30 peer-reviewed publications,
  radio detection of air showers has advanced to standard-technique
- Theoretical emission modeling solid:
  verified at SLAC accelerator,
  3 independent theoretical descriptions agree to < 10% in amplitude





SLAC T-510, PRL 116, 141103 (2016)

Track-record

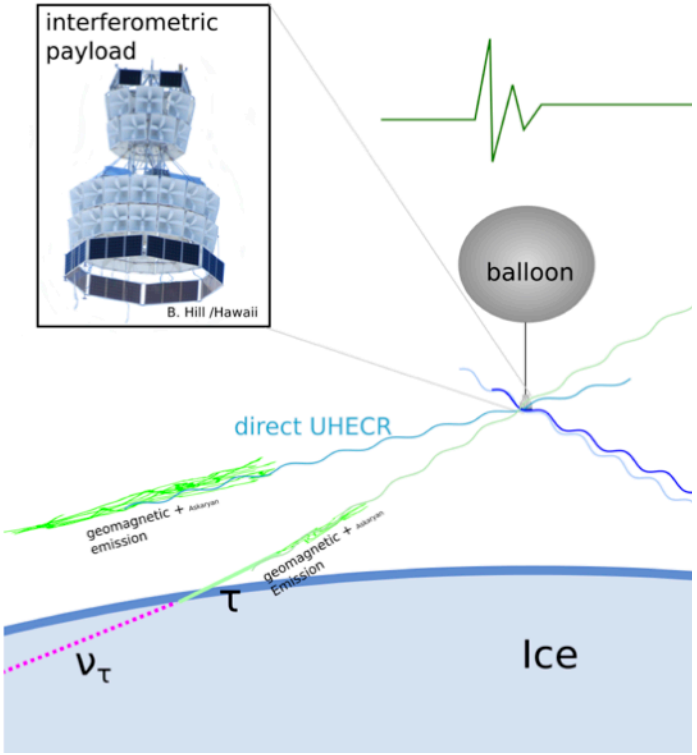
Why are we confident that this is a good plan?

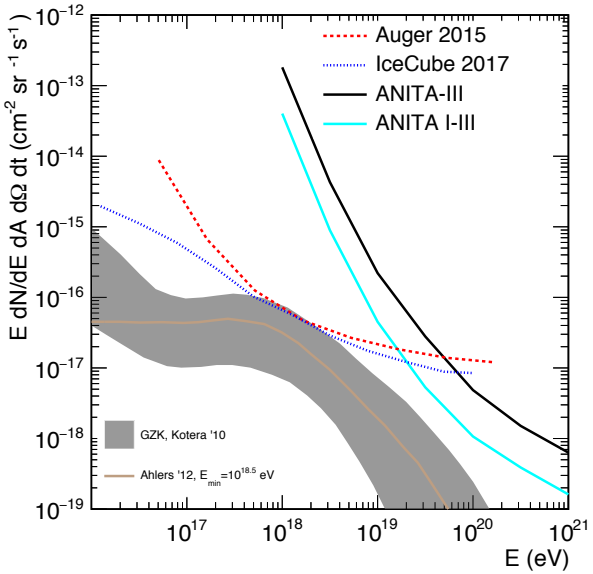
- Radio detection of showers experimentally verified in air with cosmic rays:
  > 30 peer-reviewed publications,
  radio detection of air showers has advanced to standard-technique
- Theoretical emission modeling solid:
  verified at SLAC accelerator,
  3 independent theoretical descriptions agree to < 10% in amplitude
- Pilot-arrays (ARA and ARIANNA) as well as ANITA balloon have been running soundly for the past 5 years and have passed verification tests

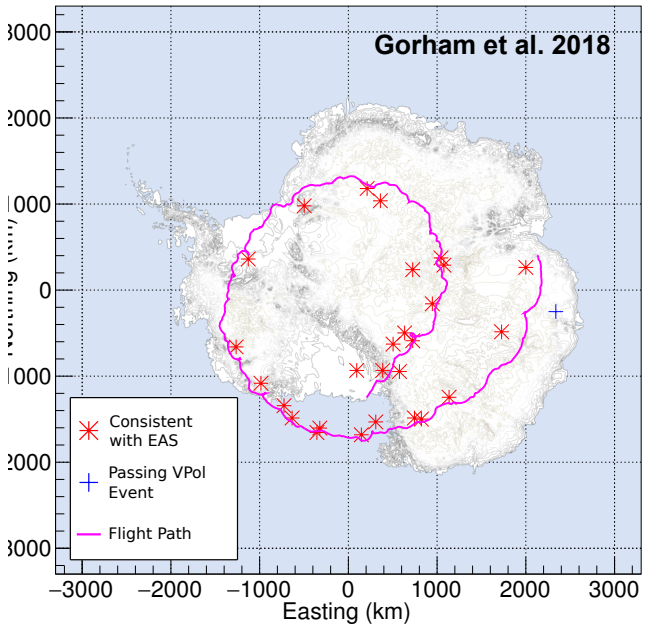
ANITA

Antarctic Impulsive Transient Antenna

- ANITA has flown 4 times over Antarctica
- Data from first three flights published
- Energy threshold > 10^{18} eV due to distance to shower
- Peculiar upward-pointing events reported, not “regular” air shower background, interpretation as tau neutrinos in strong tension with existing limits

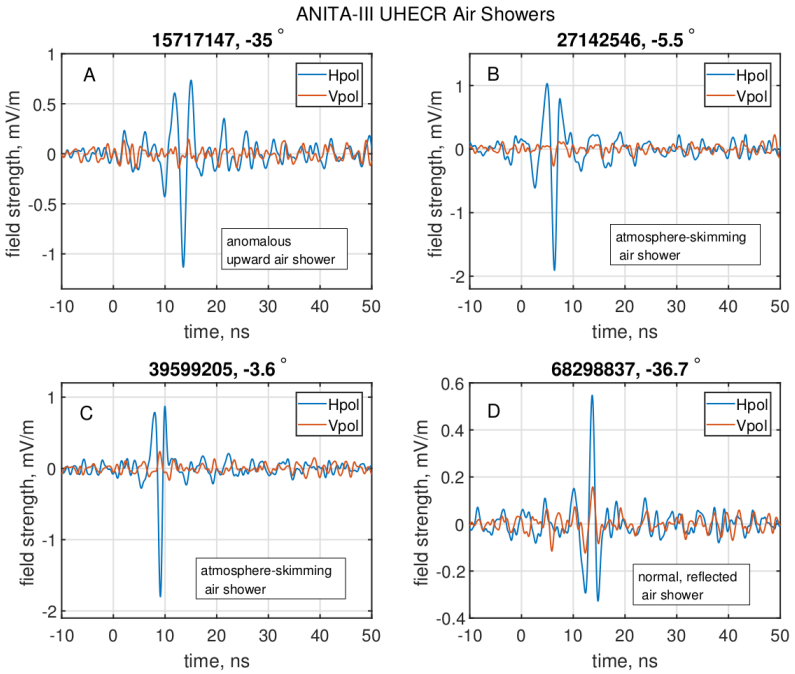






Track-record

ANITA “mystery” events



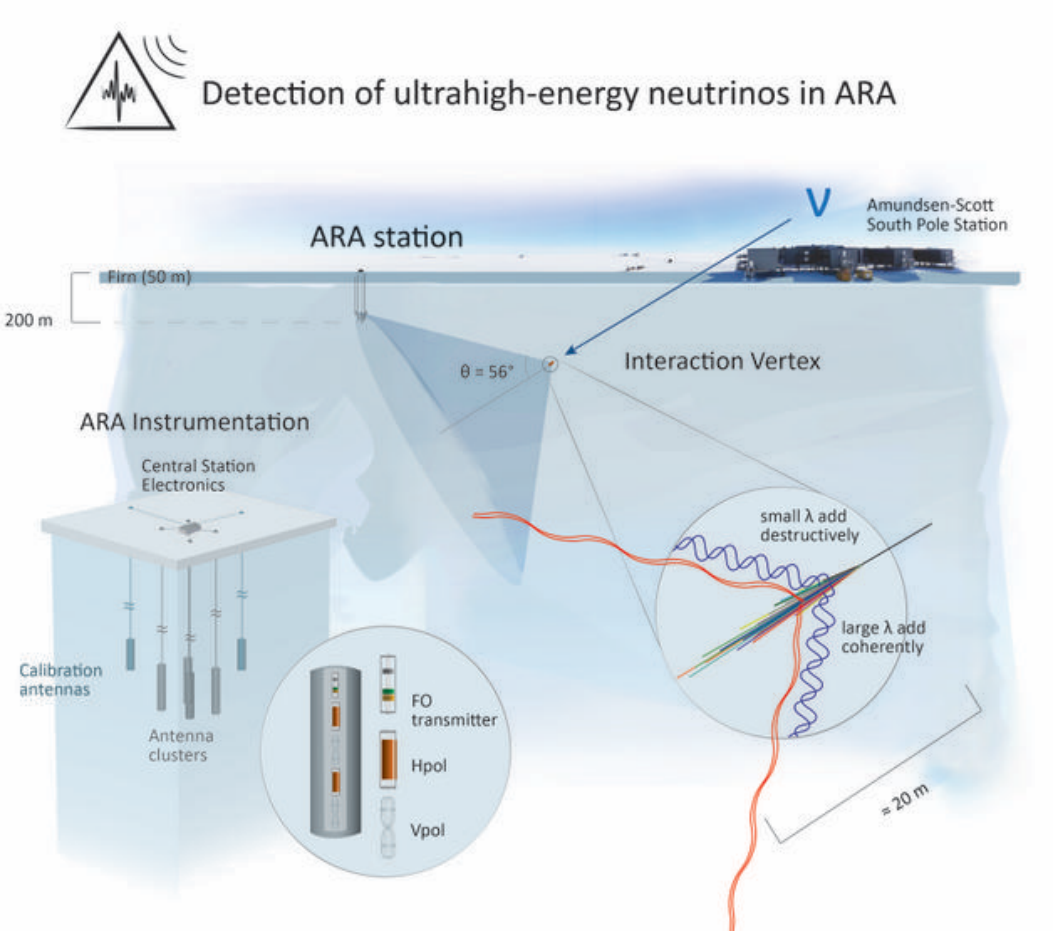
Top-Left: Anomalous A-III event
Top-Right, Bottom-Left: Direct UHECR candidates
Bottom-Right: A reflected UHECR candidate

- Anomalous events found in ANITA-I and ANITA-III (arXiv:1803.05088)
- Matches UHECR template, polarity consistent with direct cosmic ray event, but clearly points to ice
- Flurry of papers: τ candidate! (Or other exotic/new physics)
- Problem: chord length through Earth in tension with SM cross-section and flux in tension with Auger and IceCube limits
- No satisfying interpretation, many explanations besides new physics: particular reflection on ice, man-made background, electric field in clouds, …
- PUEO could solve this “mystery”

ARA

Askaryan Radio Array, South Pole

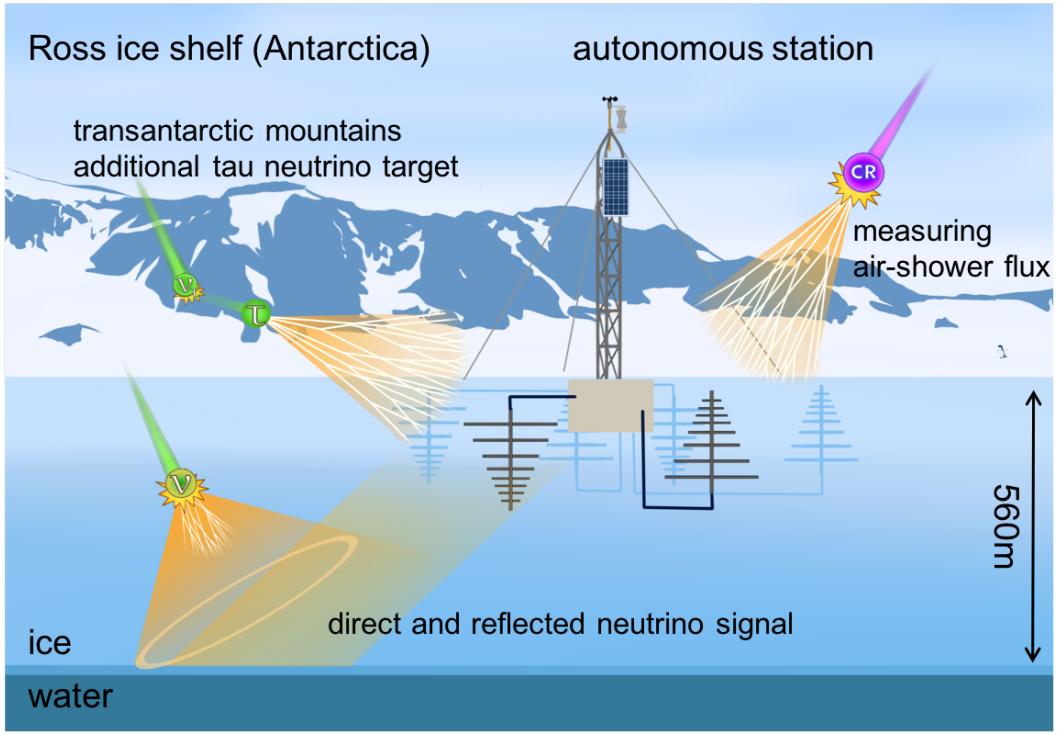
- Has been running a various configurations since 2010
- At 200 meters in the ice, compact ice, wide field of view, shielding from man-made noise at surface
- Powered by South Pole station, 100% up-time
- Data-transfer to station, low trigger thresholds, high data-volumes, analysis offline
- Design restricted by bore-hole geometry



ARIANNA

Antarctic Ross Ice-Shelf ANtenna Neutrino Array

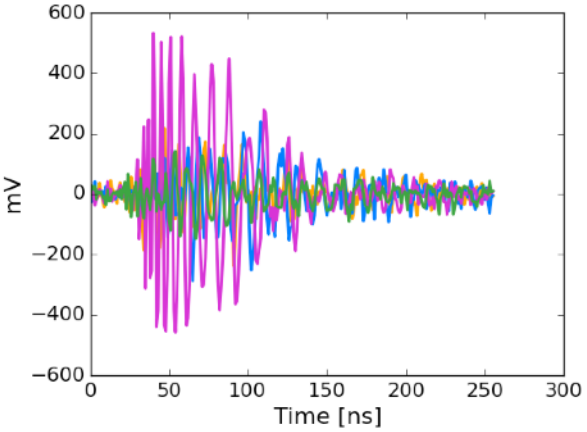
- Has been running in various configurations since 2012
- Stations are deployed close to the surface for maximum flexibility in antenna and station design
- Autonomous, light-weight stations with minimal data transferred via Iridium
- Isolated on Ross Ice-Shelf reduced man-made background
- Air showers unique calibration signal

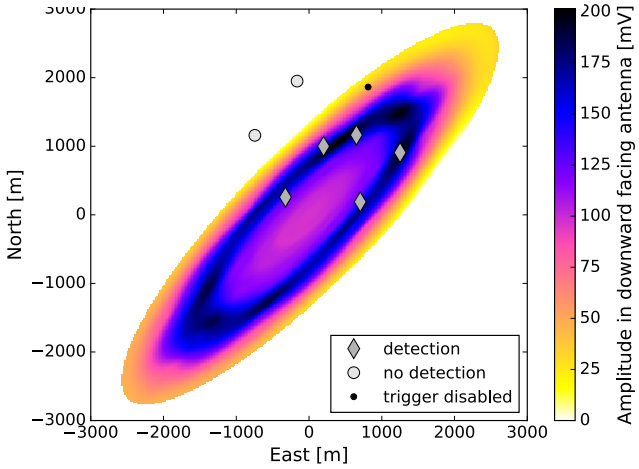


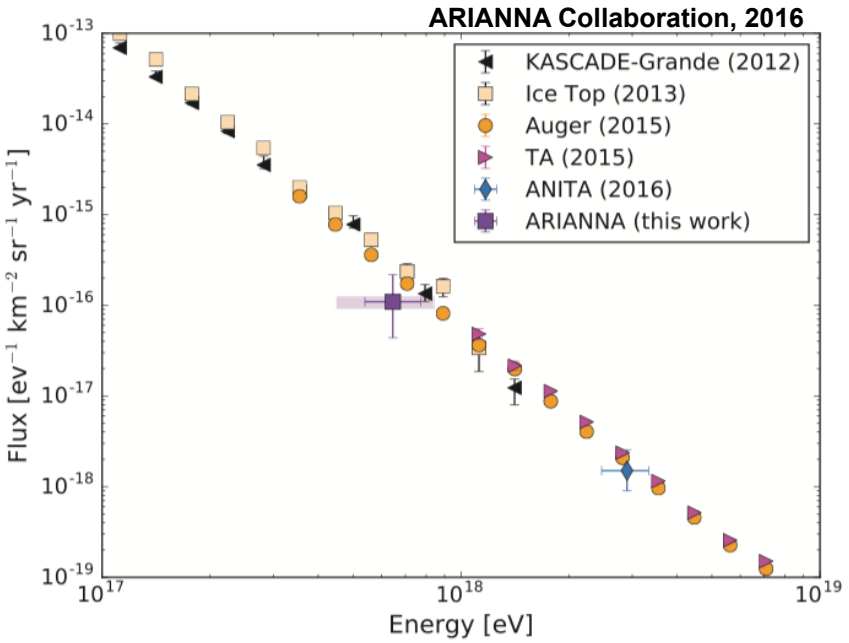
Track-record

Radio detection of neutrinos

- Cosmic ray signals identified and energy spectrum measured, proof-of-principle for detectors, triggers and detection methods



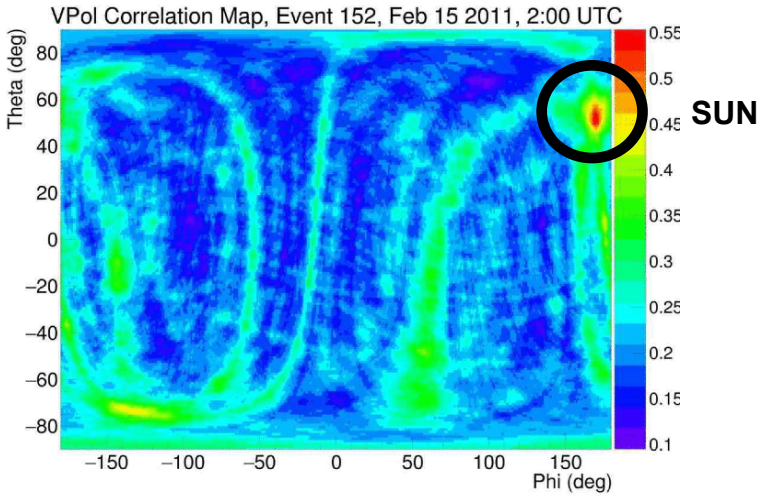




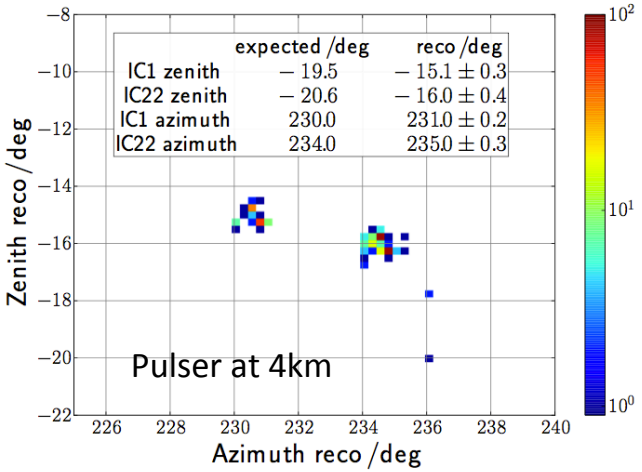
Track-record

Radio detection of neutrinos

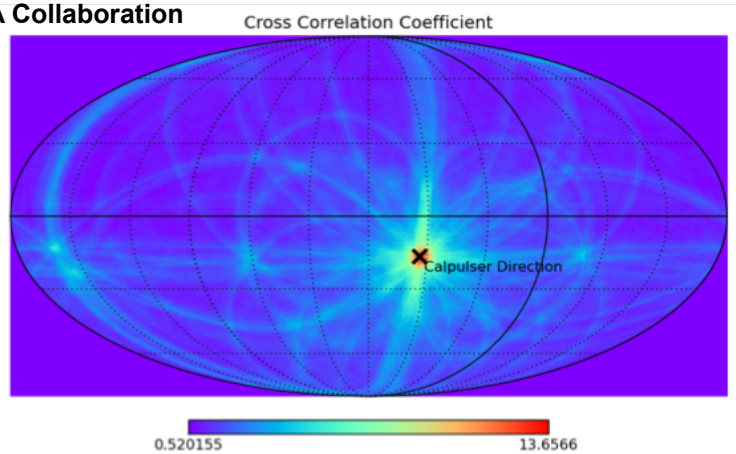
- Cosmic ray signals identified and energy spectrum measured, proof-of-principle for detectors, triggers and detection methods
- Reconstruction of calibration pulsers and solar flares



SUN



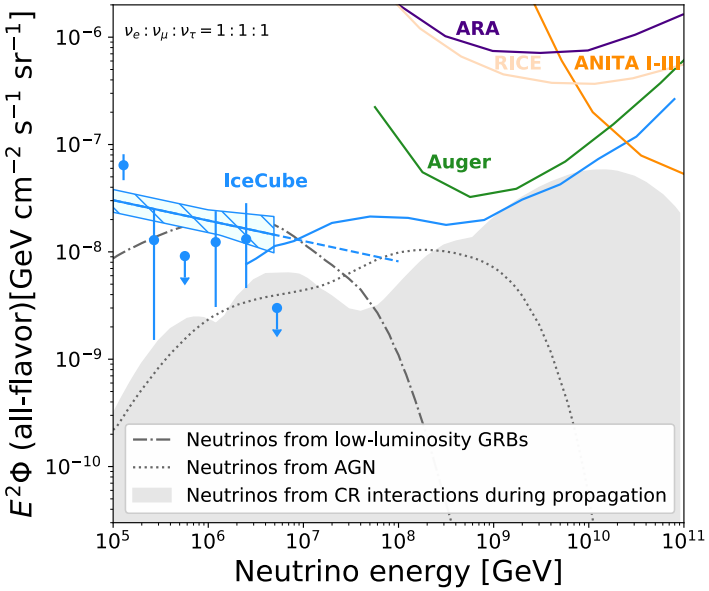
ARA Collaboration

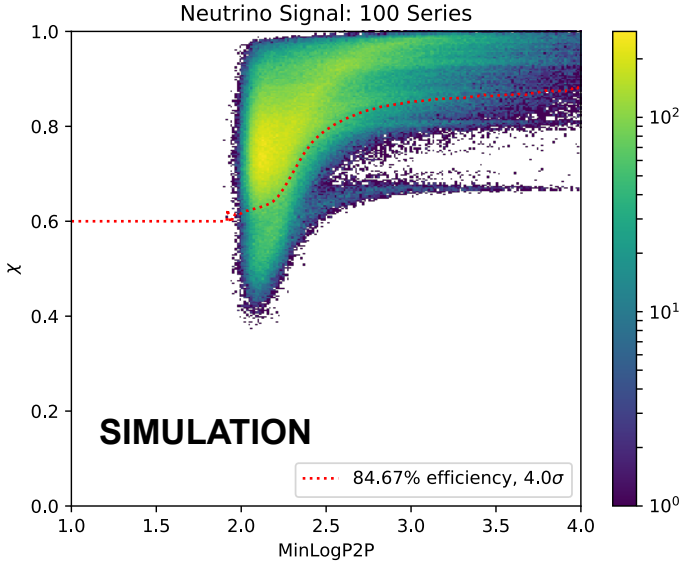


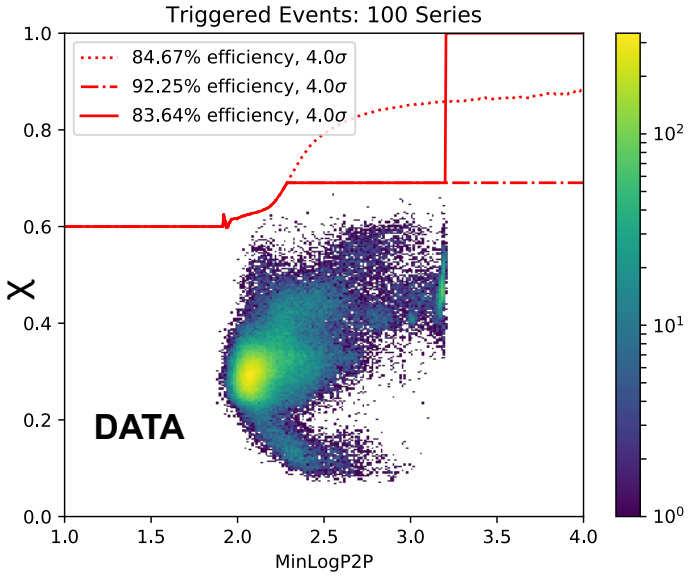
Track-record

Neutrino searches

- All precursor experiments either to small or energy threshold too high for a real chance at detecting neutrinos
- Developed successful analysis strategies
- High efficiencies and promising results



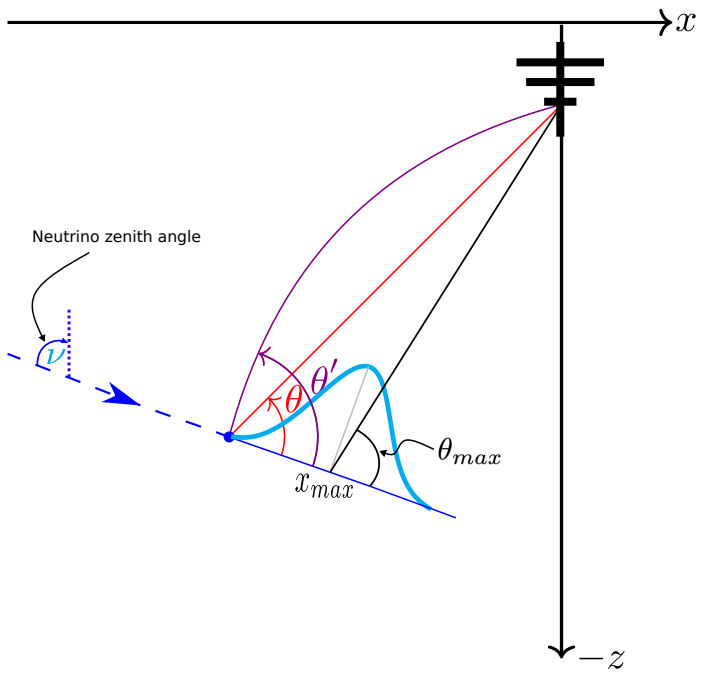


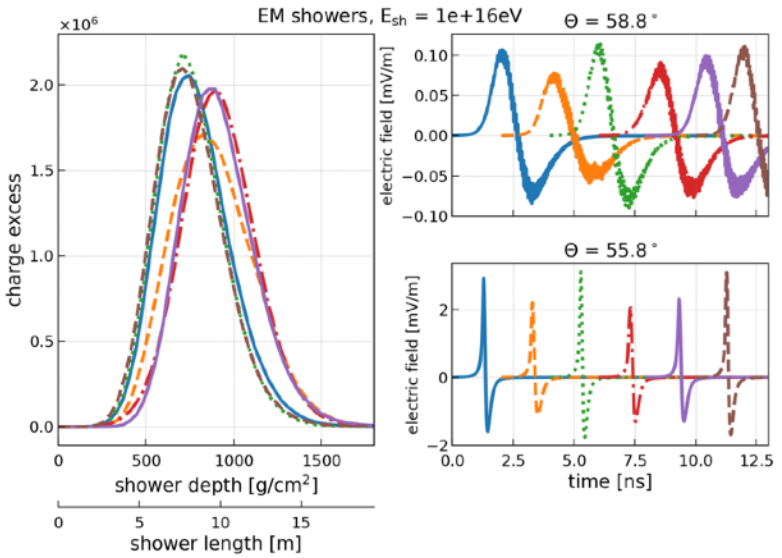


Track record

Simulation of neutrino signals

- Cosmic ray radio simulations (CoREAS, ZHAireS) have been confirmed to < 5% accuracy
- Radio emission of neutrinos same emission mechanisms, but (old) simulation codes not as sophisticated yet
- Signal propagation in ice more complicated, LPM effect, Tau neutrinos, …
- Modern software for neutrinos: **NuRadioMC**
- Extensive community-wide discussion and implementation (“InIceMC working group”)
- First release coming soon

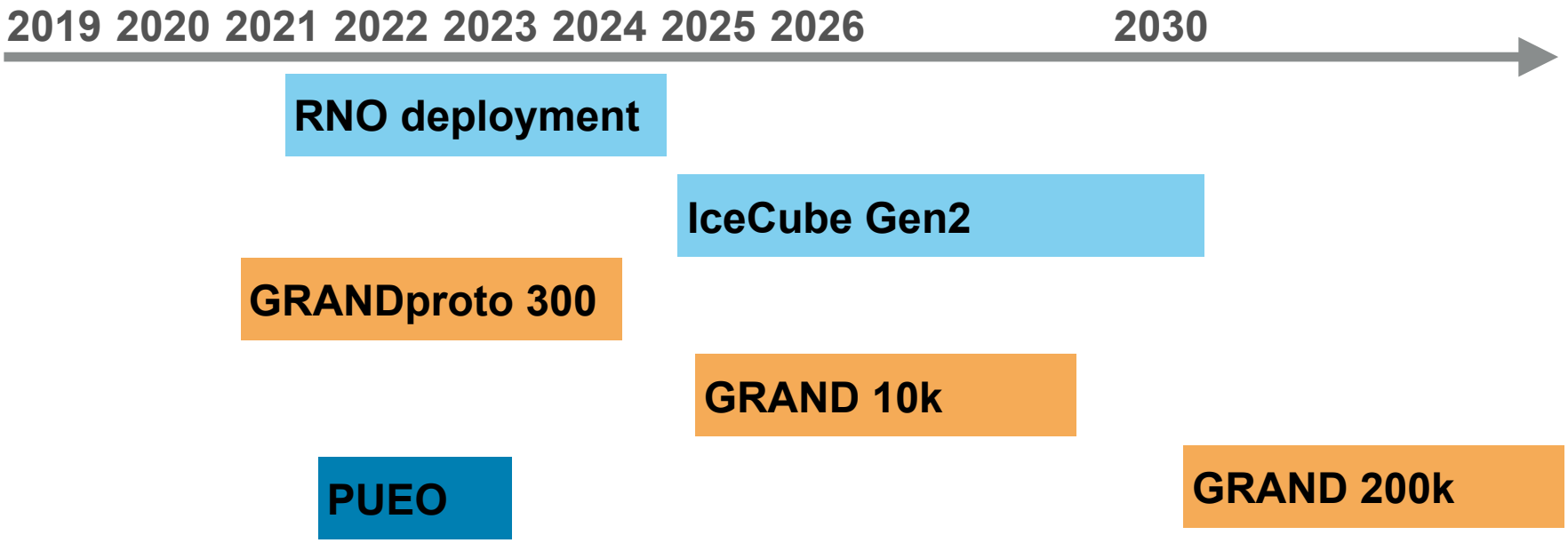




Timelines and perspectives

What could happen

- All precursor experiments either to small or energy threshold too high for a real chance at detecting neutrinos
- Large experiments needed to reach science goals: some of the proposed time-lines



Conclusions

Radio Detection of neutrinos: status and perspectives

- Radio detection of neutrinos builds on solid theoretical modeling and successful track-record in experimental techniques
- None of the experiments has been large enough for detection of neutrinos
- In ice detectors show best sensitivity for neutrinos
- Personal: Looking forward to RNO