The Radio Neutrino Observatory in Greenland (RNO-G): Prospects and status

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KICP 20th Anniversary
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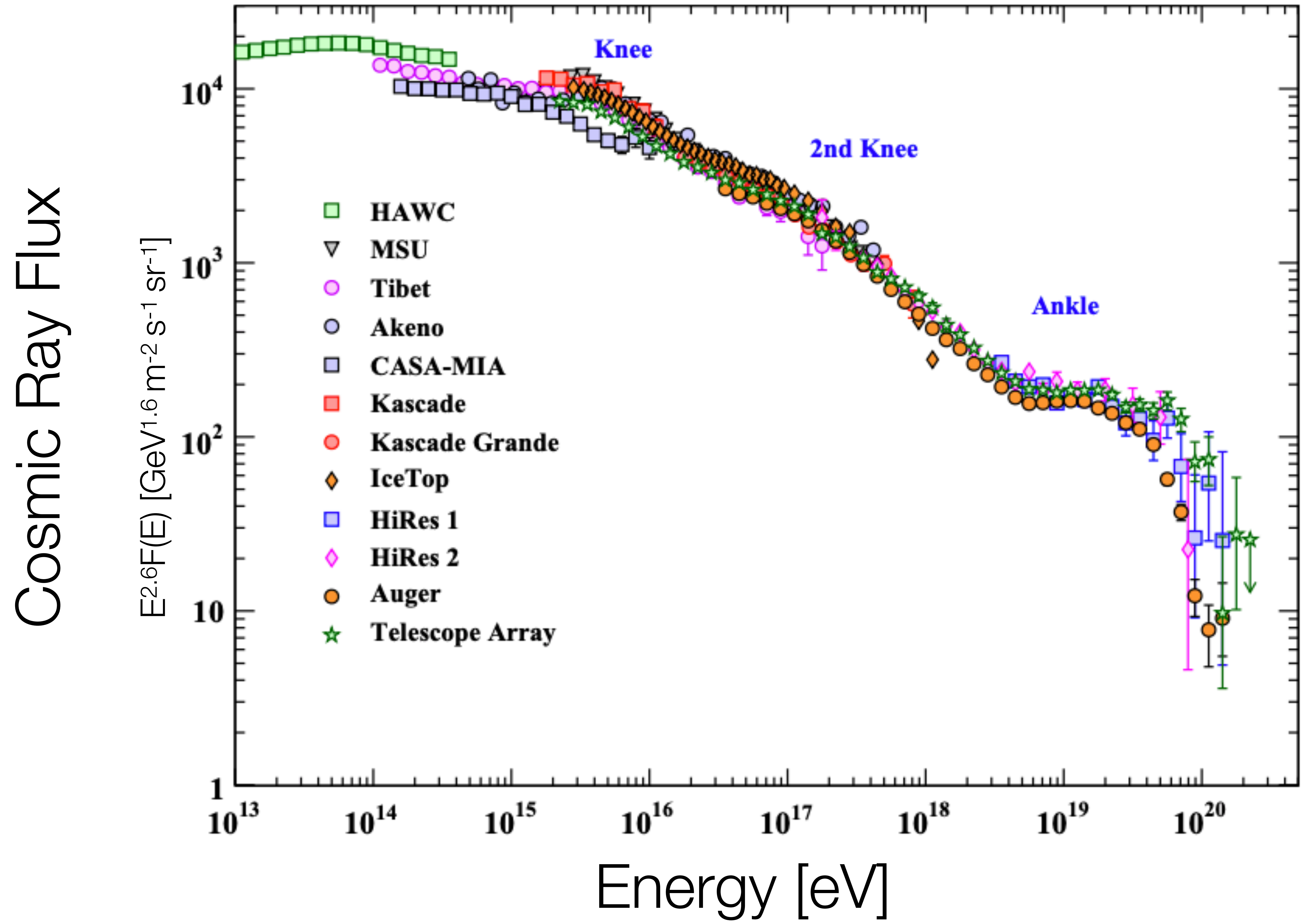
Summit Station, Greenland

My Time at KICP

- Graduate Student: 2017-2022
- KICP Associate Fellow: 2022-2022
- I am so grateful for my time here at KICP and it's great to be back!

From the PDG

The Cosmic Ray Mystery



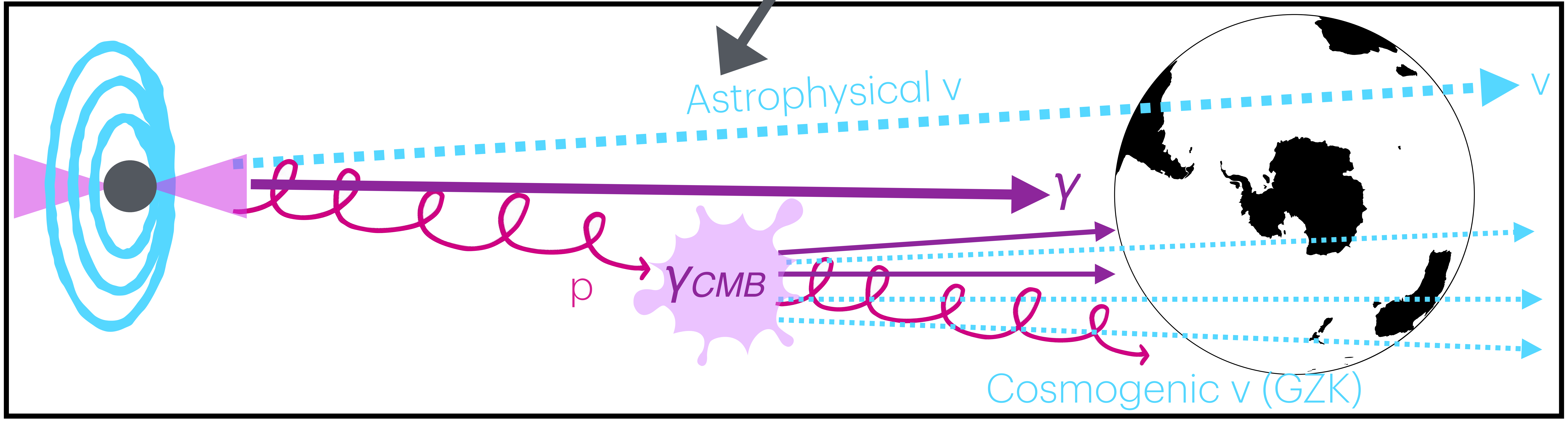
Where are the highest energy cosmic rays coming from?

Cosmic ray challenges:

- They don't point back to their sources due to magnetic fields
- They may interact as they propagate through the universe

What about neutrinos?

Produced from ultra-high energy sources via cosmic ray interactions (p-p,p-γ)



Produced by interactions between ultra-high energy cosmic rays and cosmic microwave background photons (e.g. GZK Mechanism)

“Ultra-high energy” = 10^{15} eV and above

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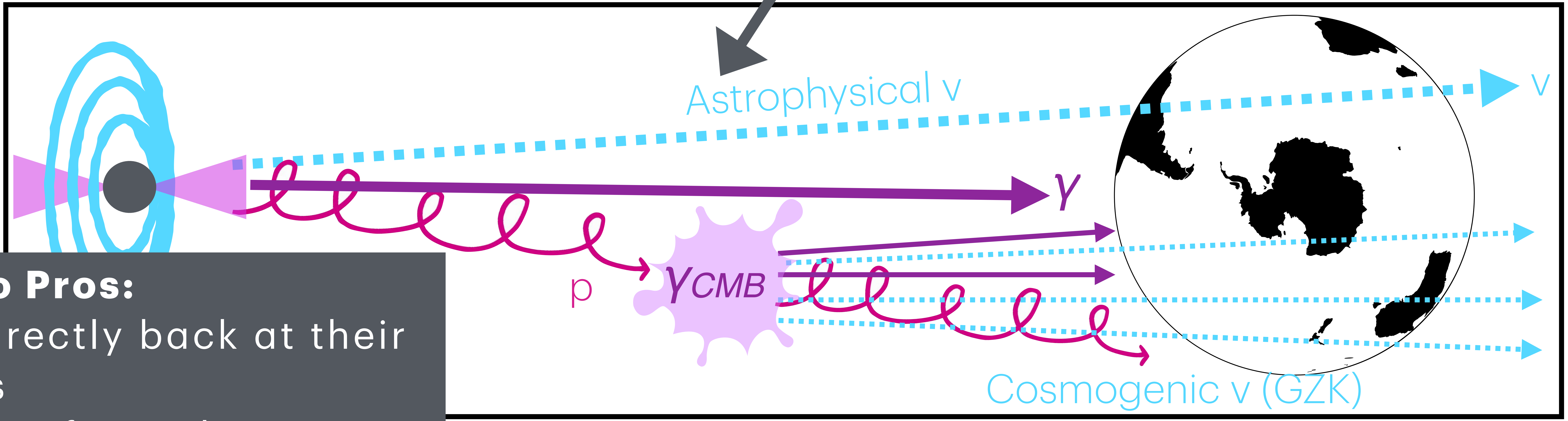

Neutrino Pros:

- Point directly back at their sources
- Capable of traveling extreme distances without interacting

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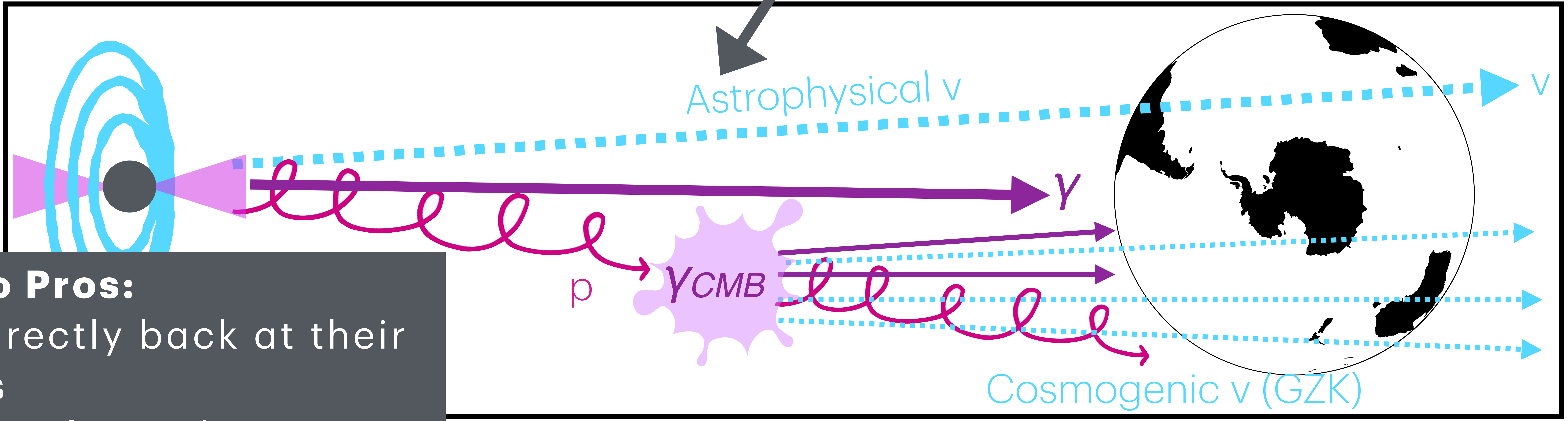


Neutrino Pros:

- Point directly back at their sources
- Capable of traveling extreme distances without interacting

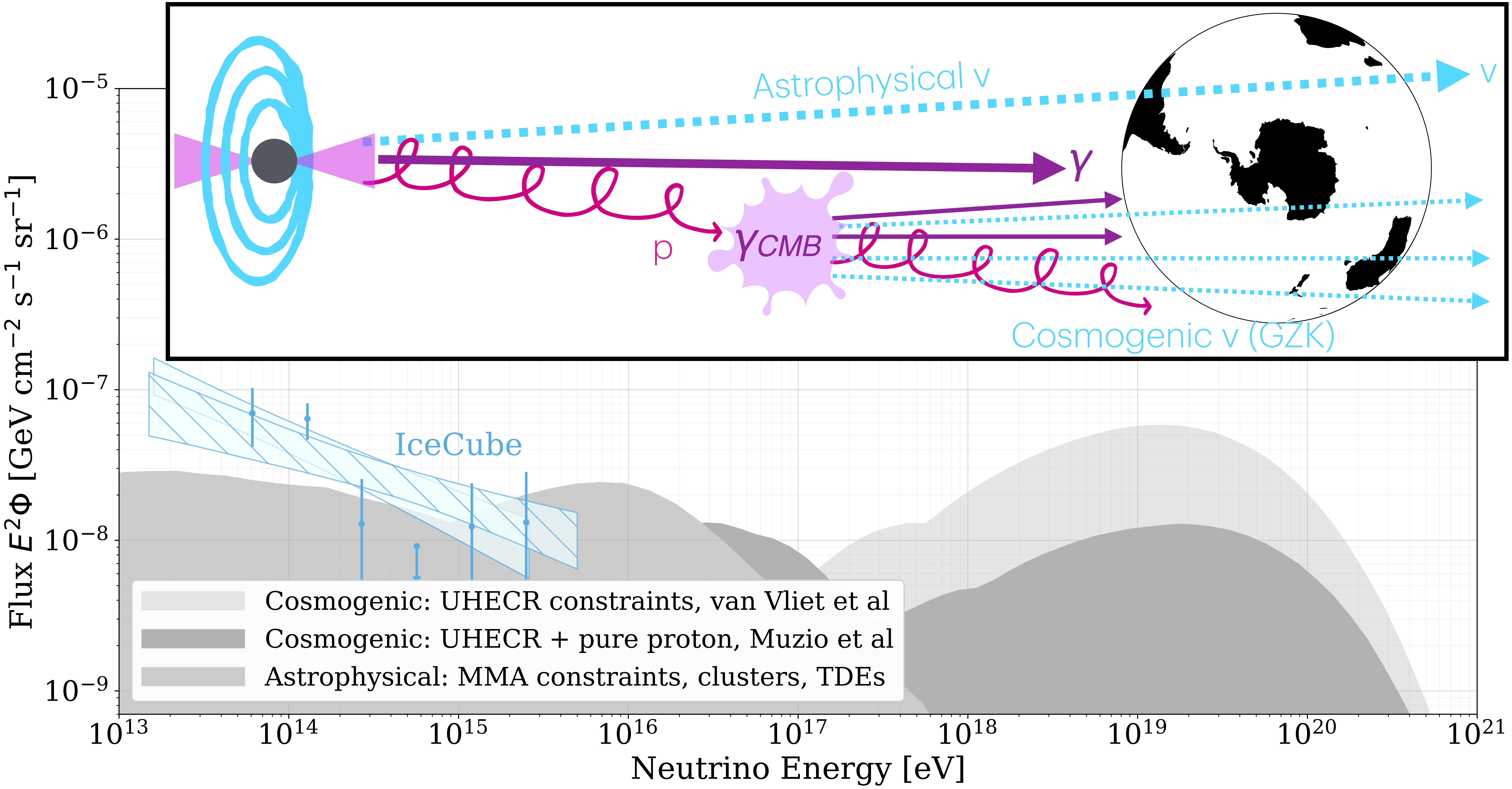
Neutrino Cons:

- Capable of traveling straight through the Earth without interacting

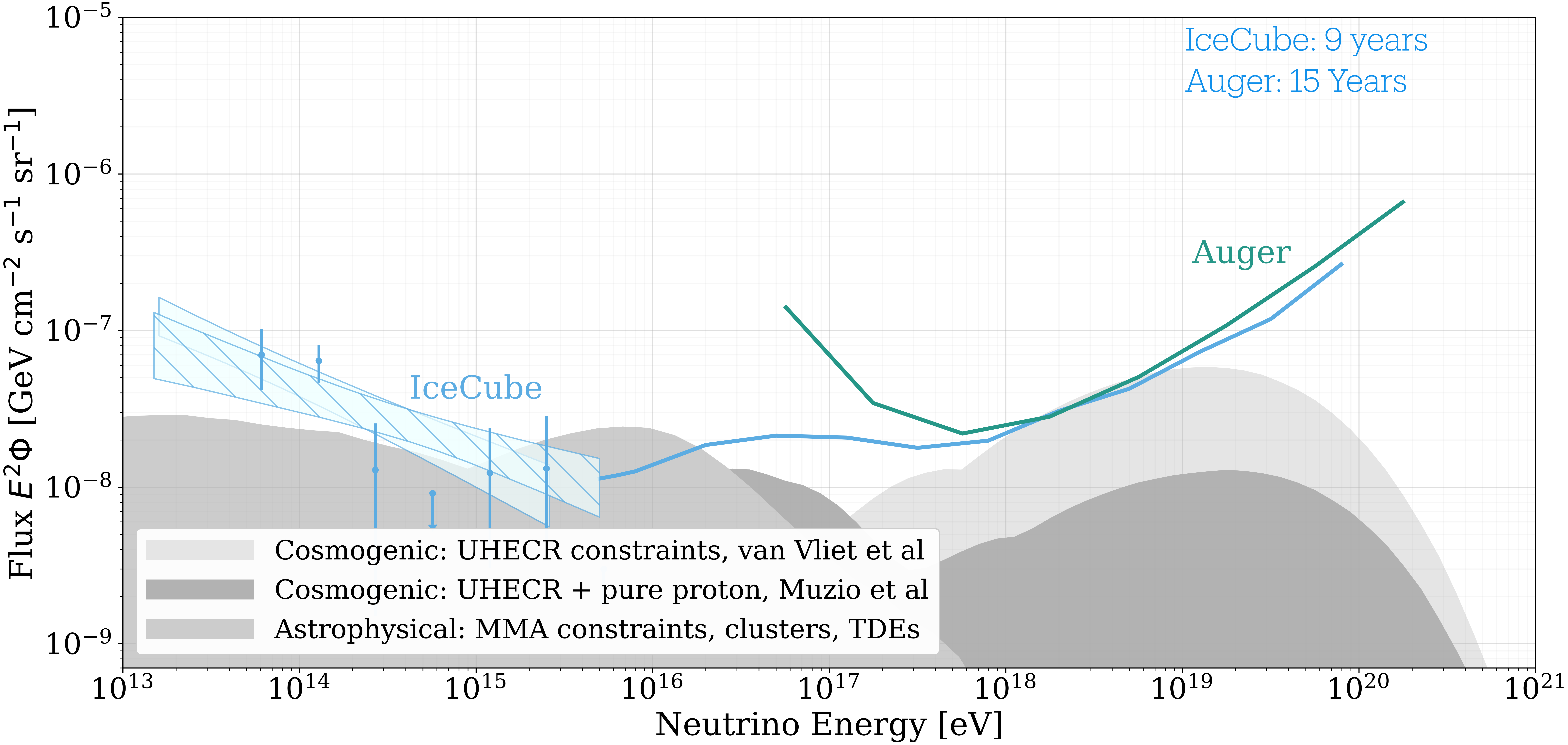
Produced by interactions between ultra-high energy cosmic rays and cosmic microwave background photons (e.g. GZK Mechanism)

Science, Vol 342, Issue 6161 (2013)

Neutrinos are expected at higher energies



We need new strategies to look at higher energies



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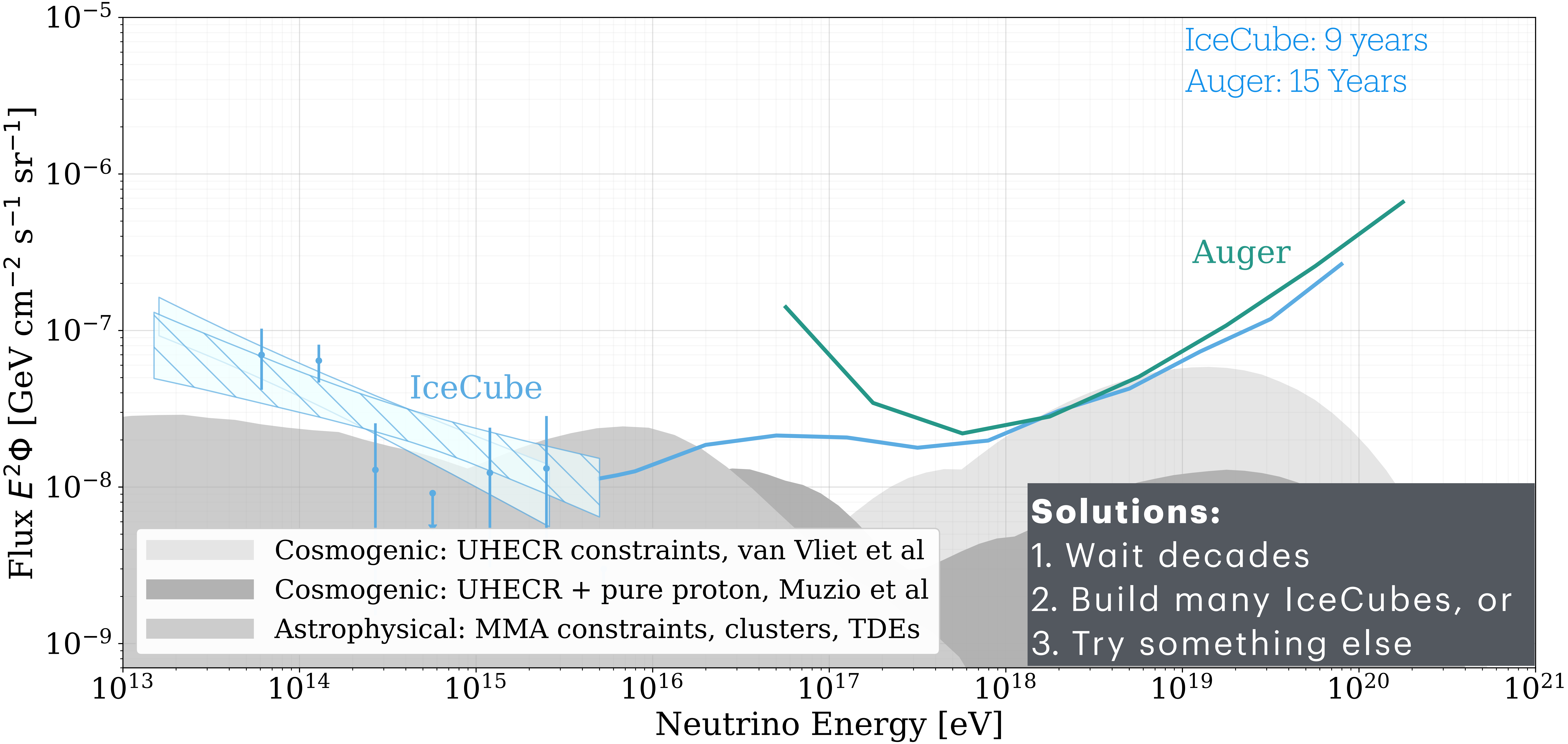


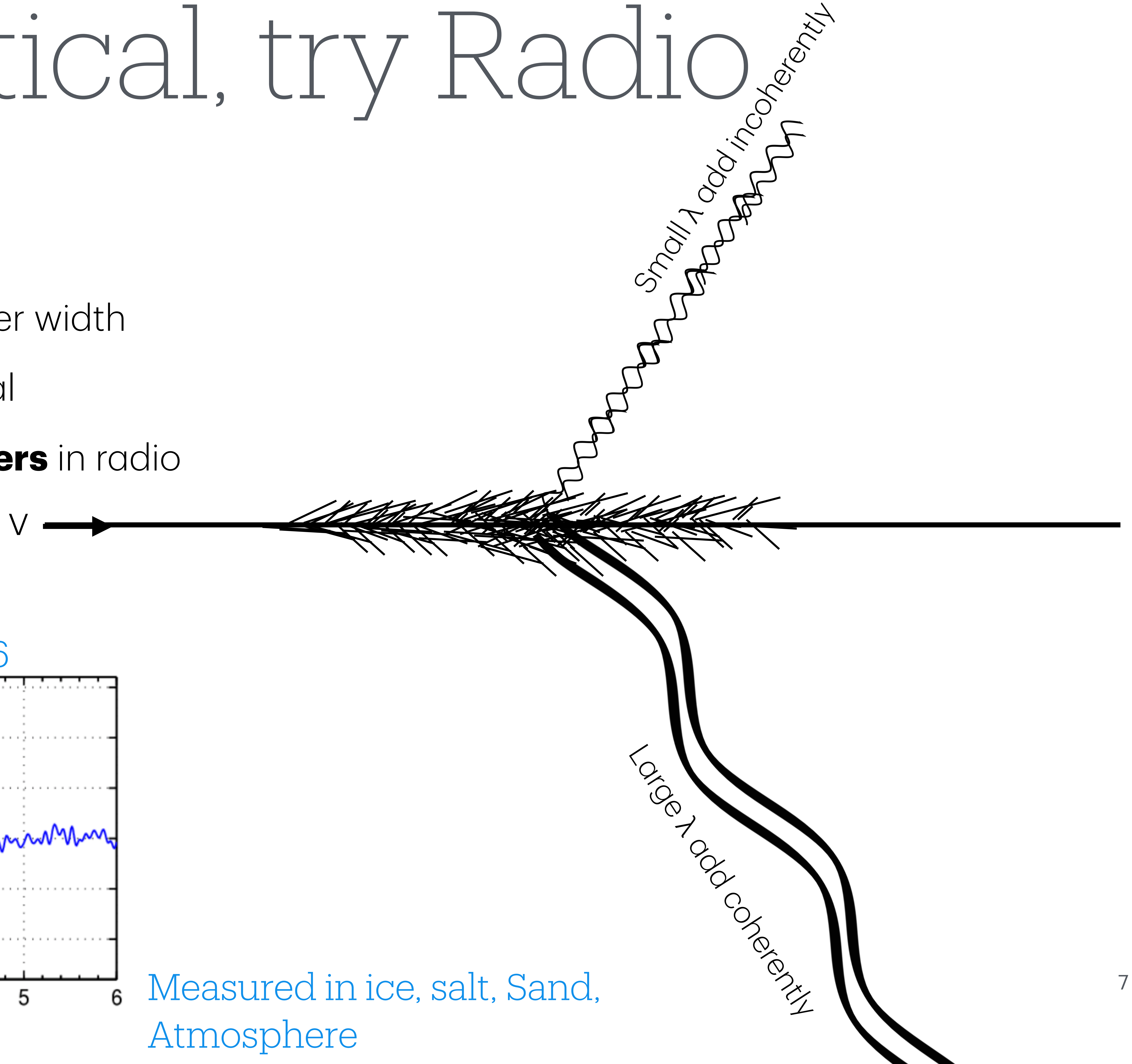
Solutions:

1. Wait decades
2. Build many IceCubes, or
3. Try something else

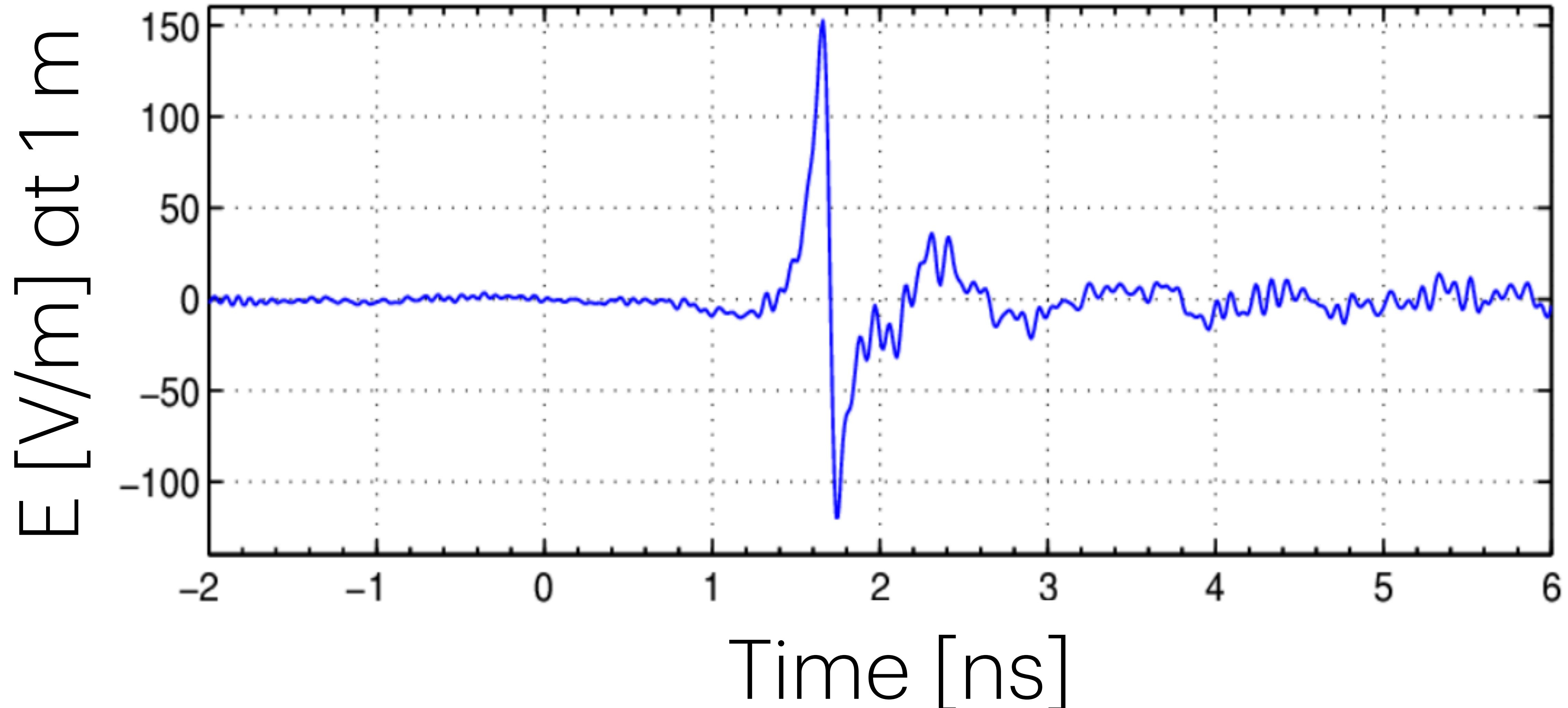
Instead of Optical, try Radio

Askaryan Radiation:

- Shower develops negative charge excess
- Coherent radiation for wavelengths > shower width
- Best in dense, dielectric, radio-clear material
- Ice attenuation: **meters** in optical, **kilometers** in radio

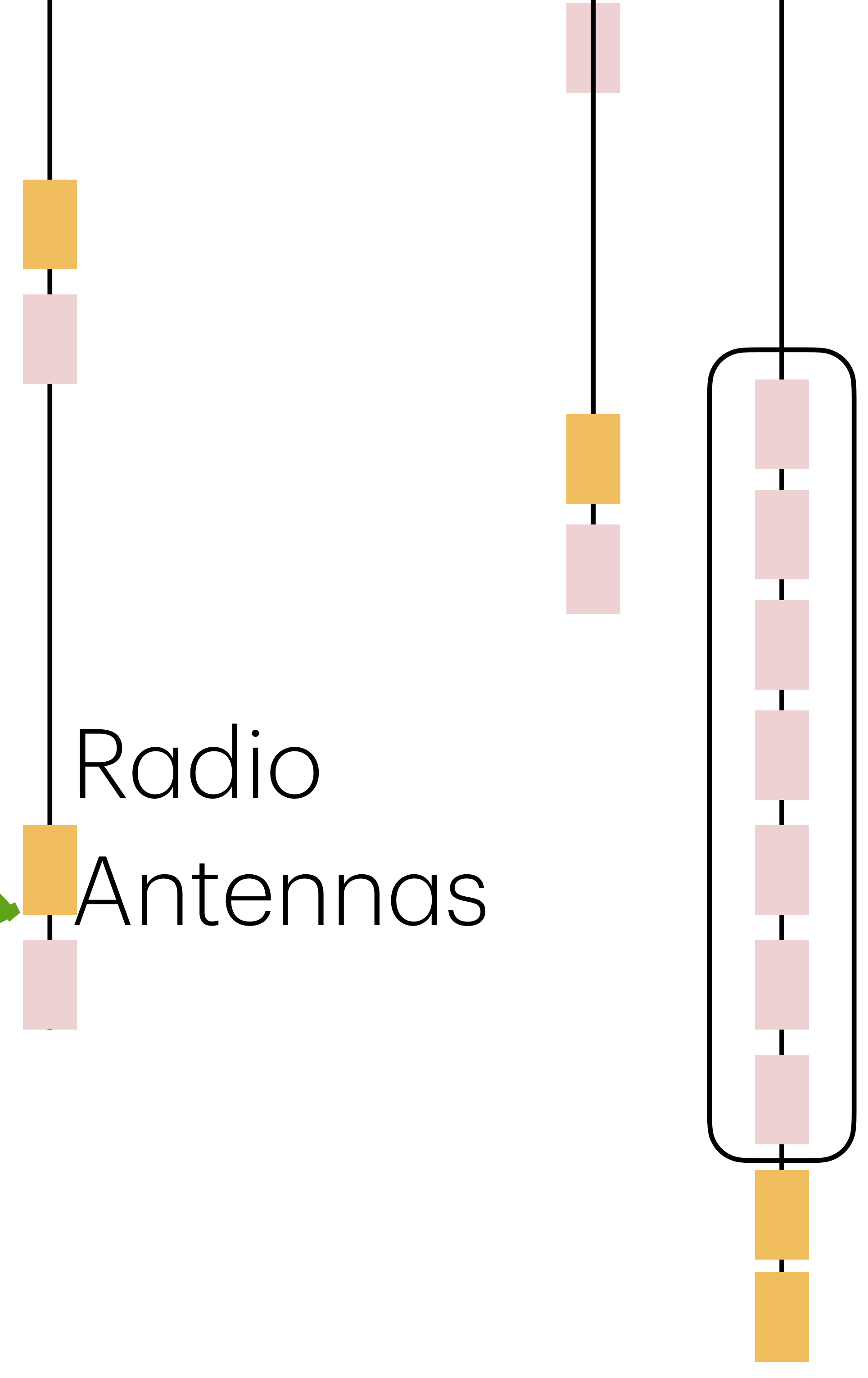


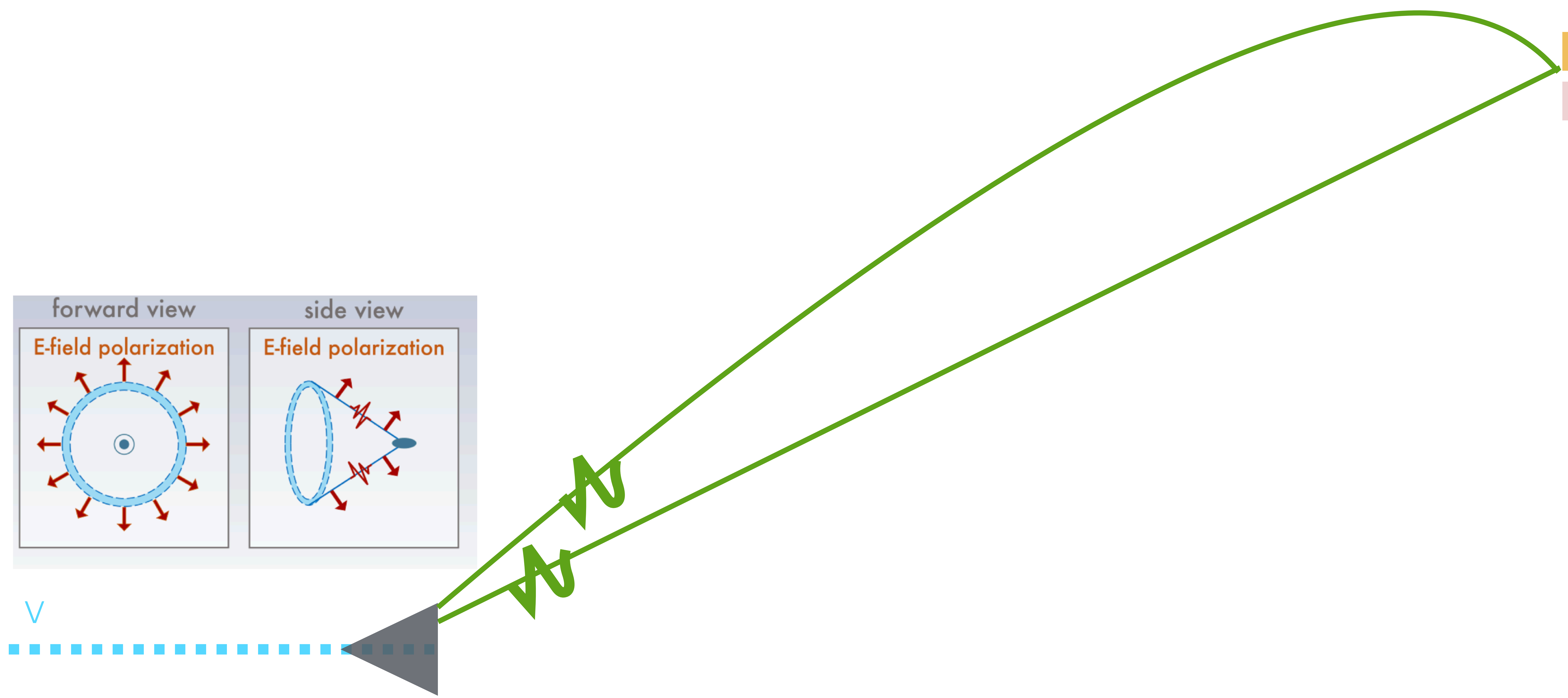
ANITA Collaboration, PRL 2006



Measured in ice, salt, Sand, Atmosphere

Expected Neutrino Signatures

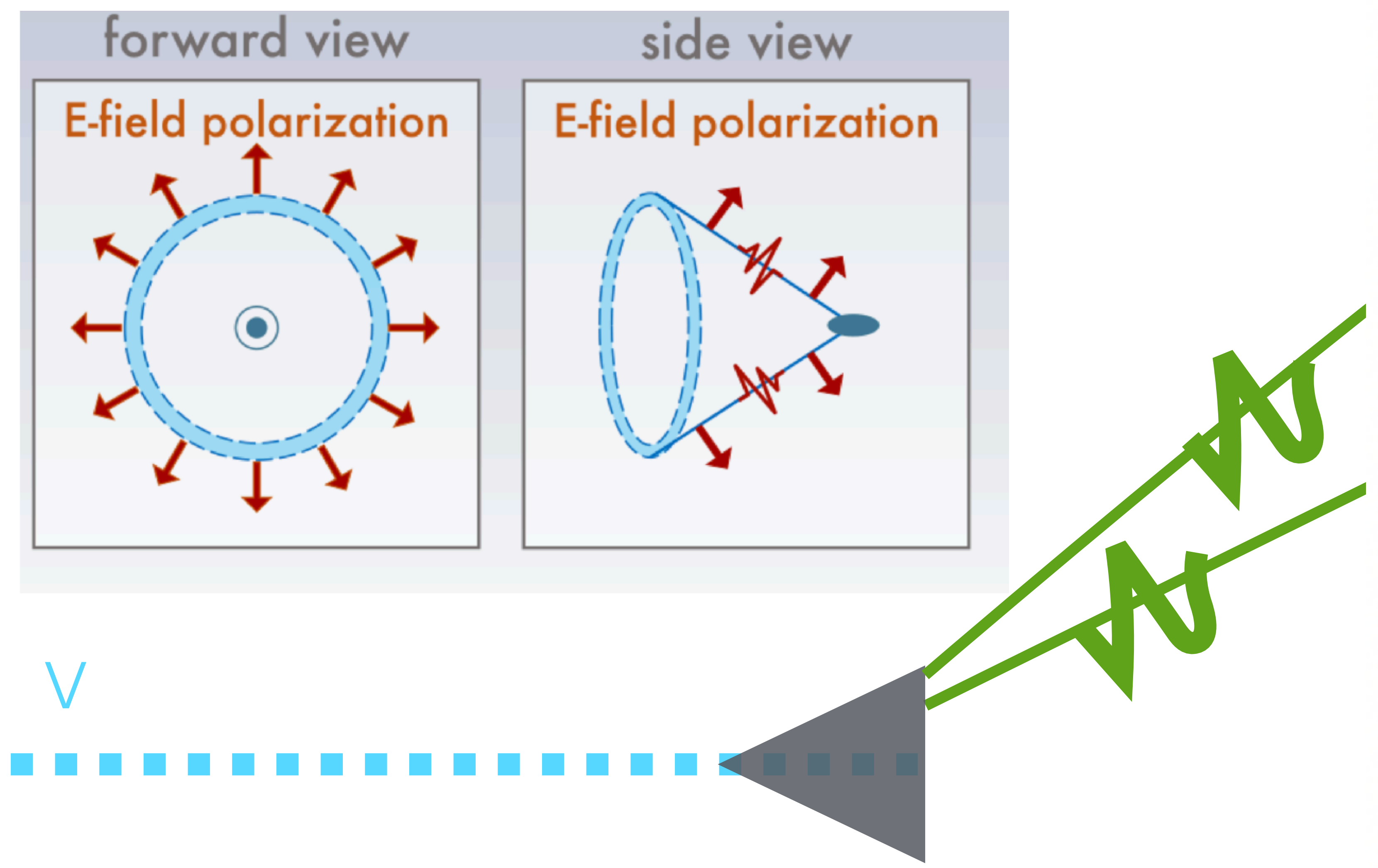


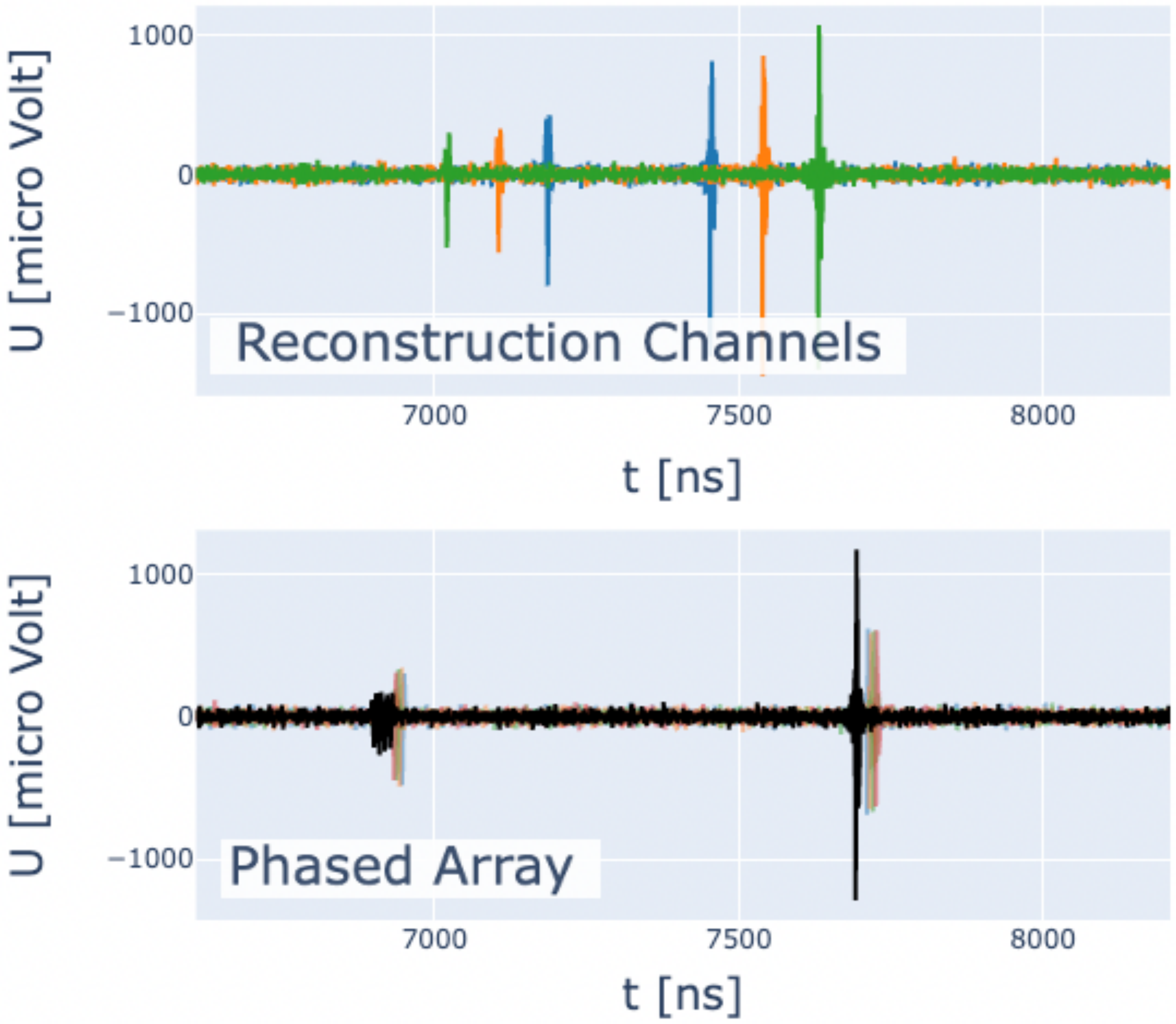


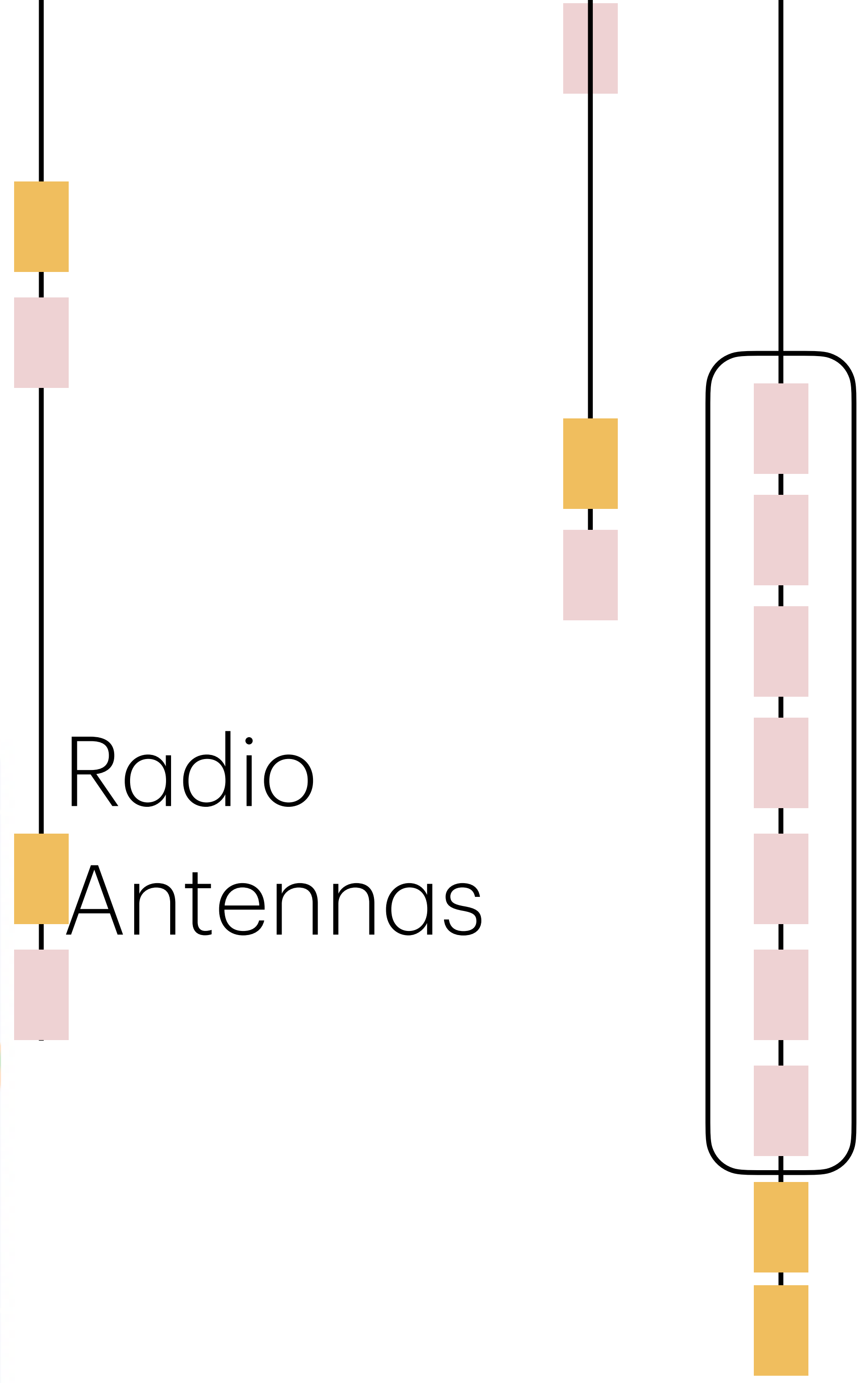
Expected Neutrino Signatures

Neutrino Event Signatures:

- Impulsive
- MHz-GHz range
- Likely originates from deep ice



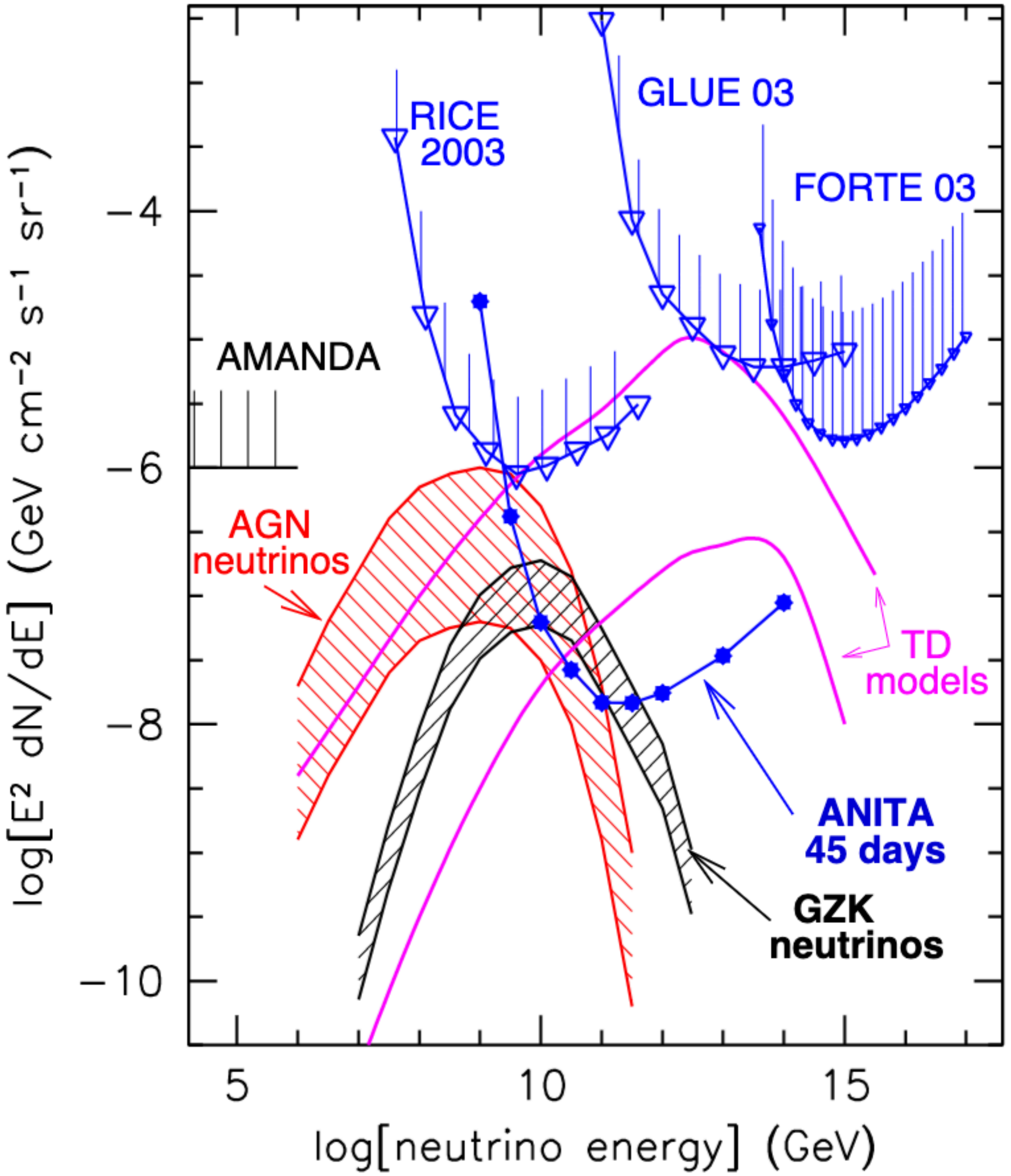




Lots of Radio-Based Experiments

Where were we 20 years ago?

RICE, GLUE, FORTE had best neutrino limits

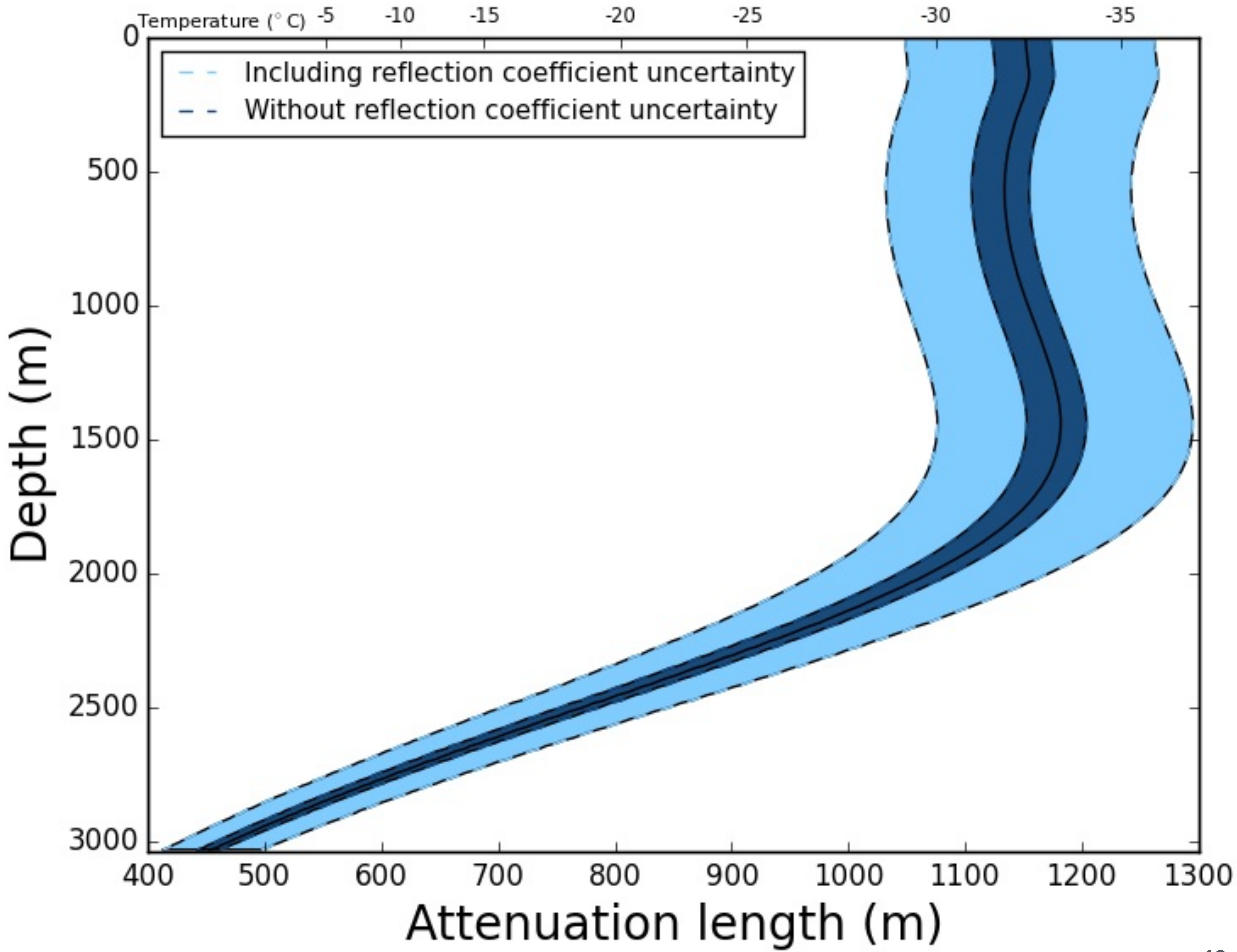


The RNO-G Collaboration (2024)

J. Avva, J. M. Kovac, C. Miki, D. Saltzberg, A. G. Vieregg (2015)

First step: pick a site

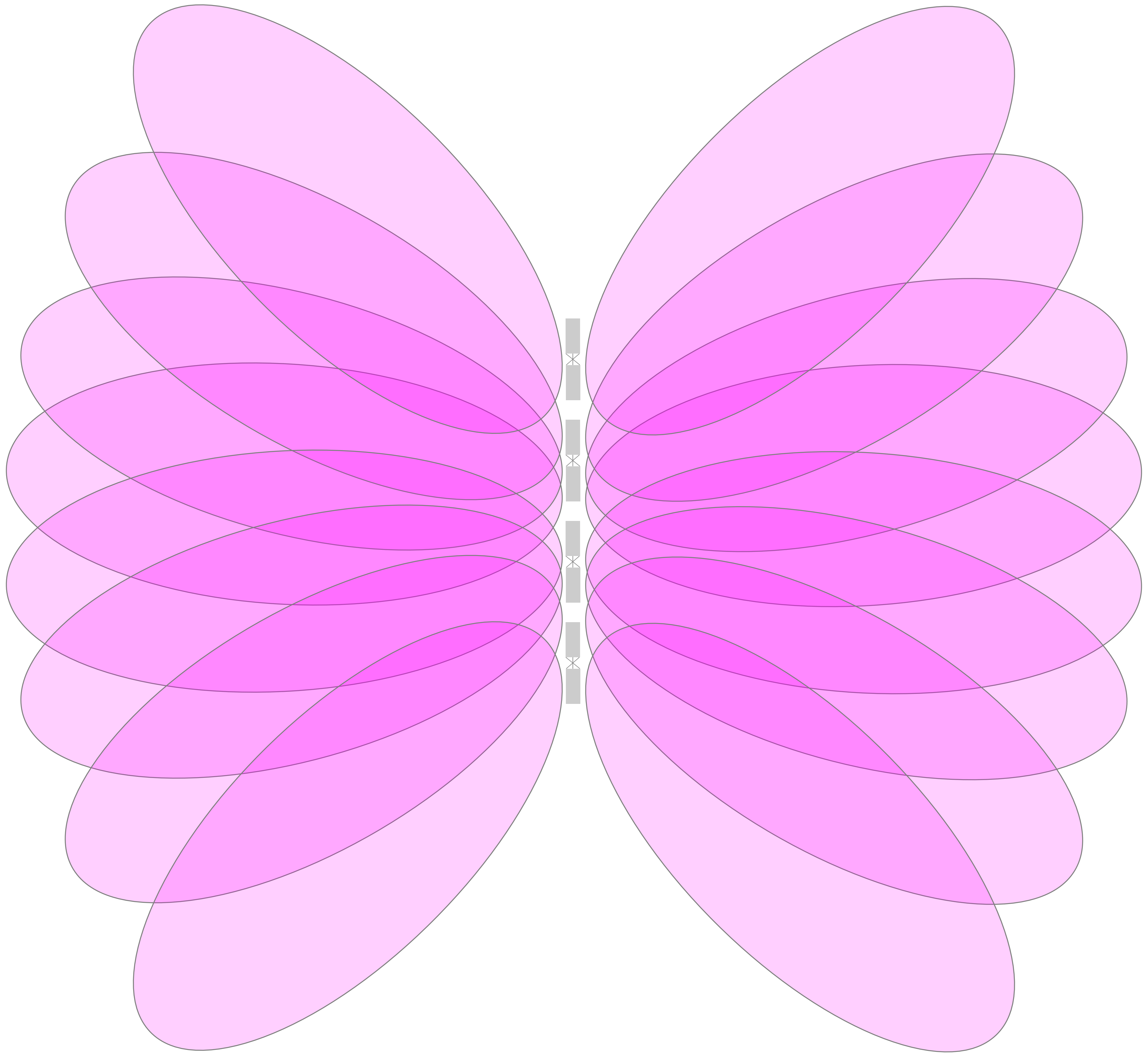
- Need somewhere with a lot of radio-clear ice
- South Pole can be logistically hard. Are there other options?
- First tests of radio response of ice in Greenland near Summit Station helped inform future designs- a team with lots of KICP ties!



Second step: prototyping

- Typical triggers had focused on power: looking for coincident power within a given time window on multiple antennas
- Instead, try a trigger with power + direction and a compact antenna design
- Define directions ahead of time and try all directions simultaneously
- Plane wave signals will add coherently -> improved trigger efficiency for smaller signals

Phased Array Triggering: Power + Direction



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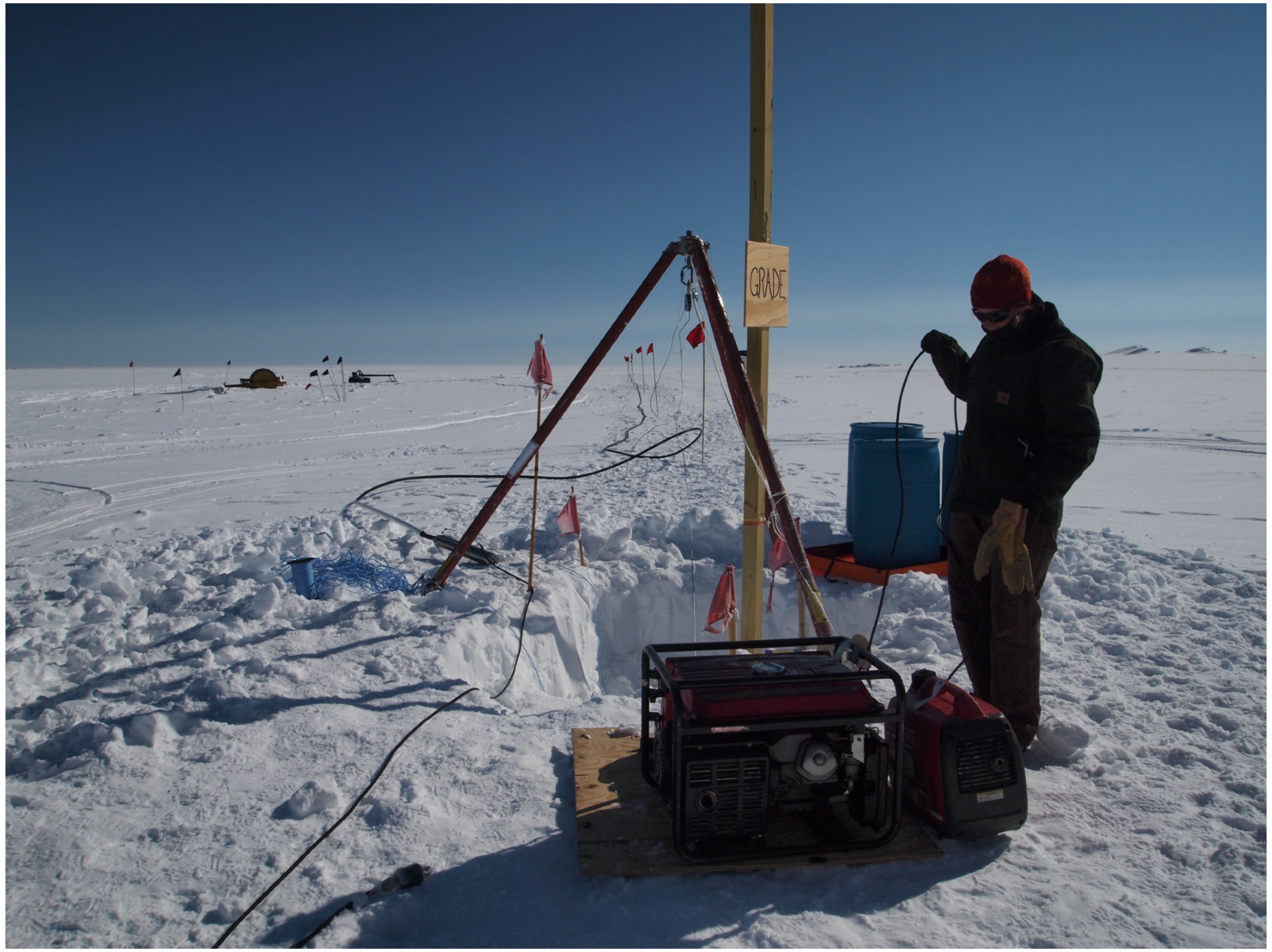
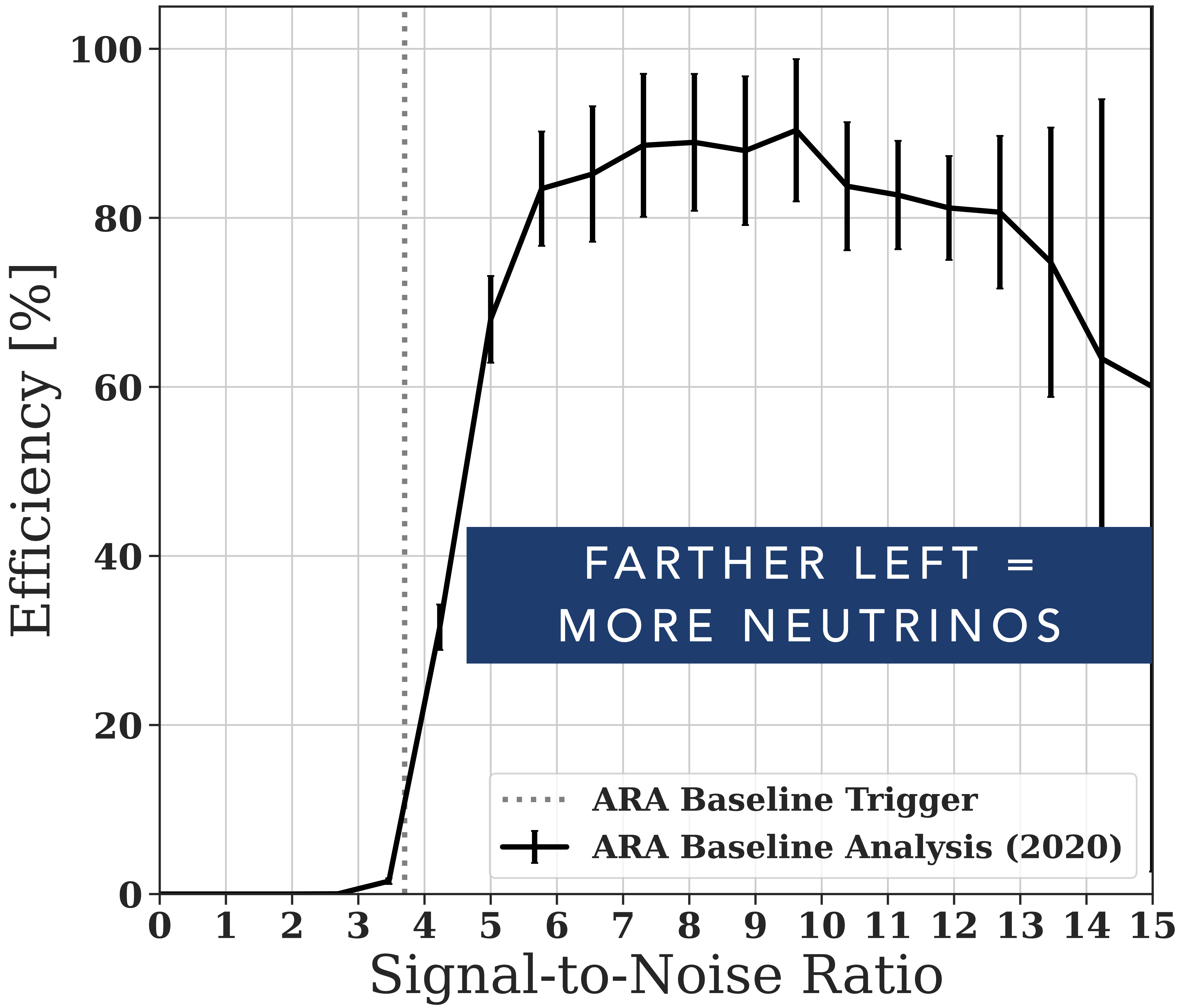
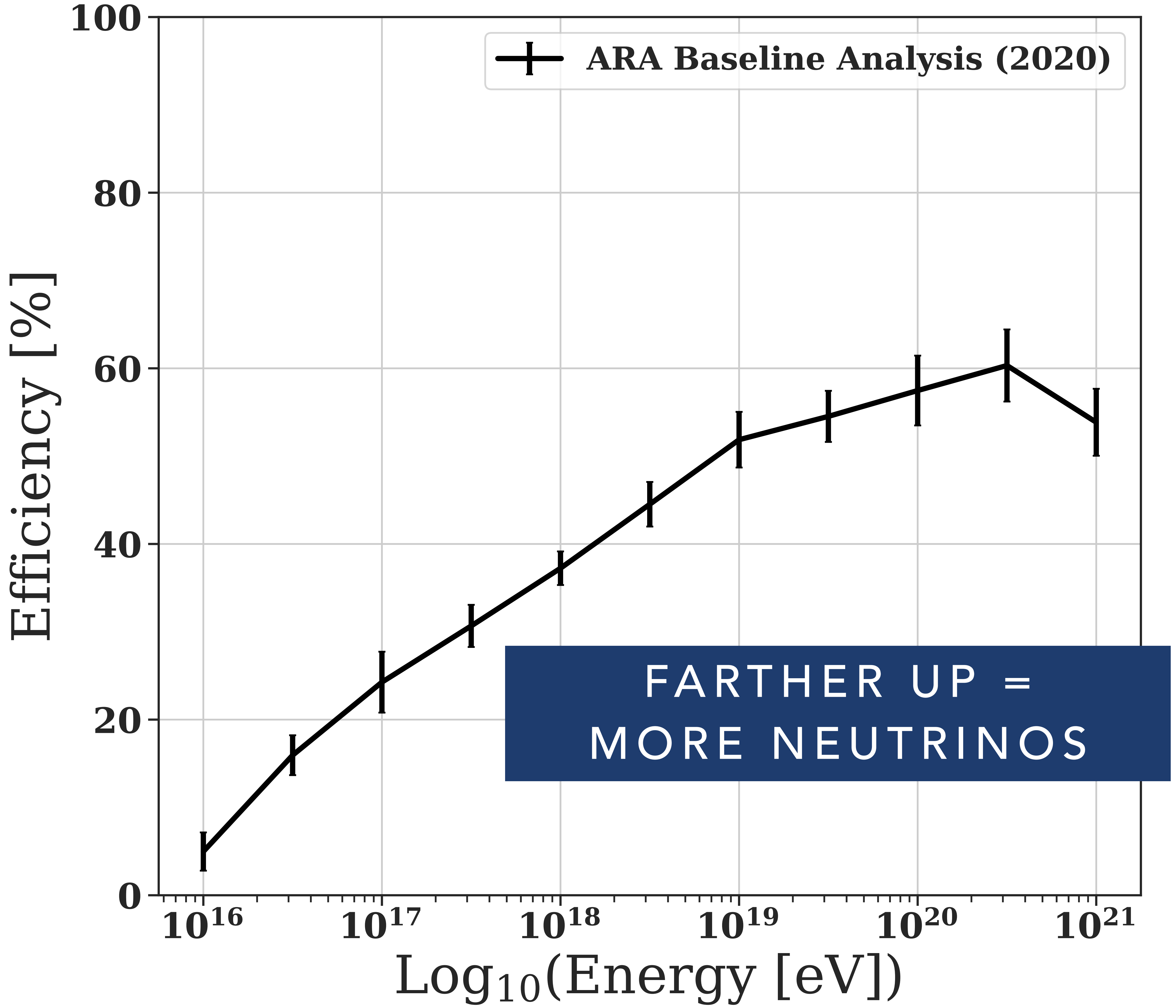


Abby testing the first iteration of a phased array trigger- Summit Station, Greenland

Me, at the South Pole testing the South Pole iteration of the phased array trigger

Second step: prototyping





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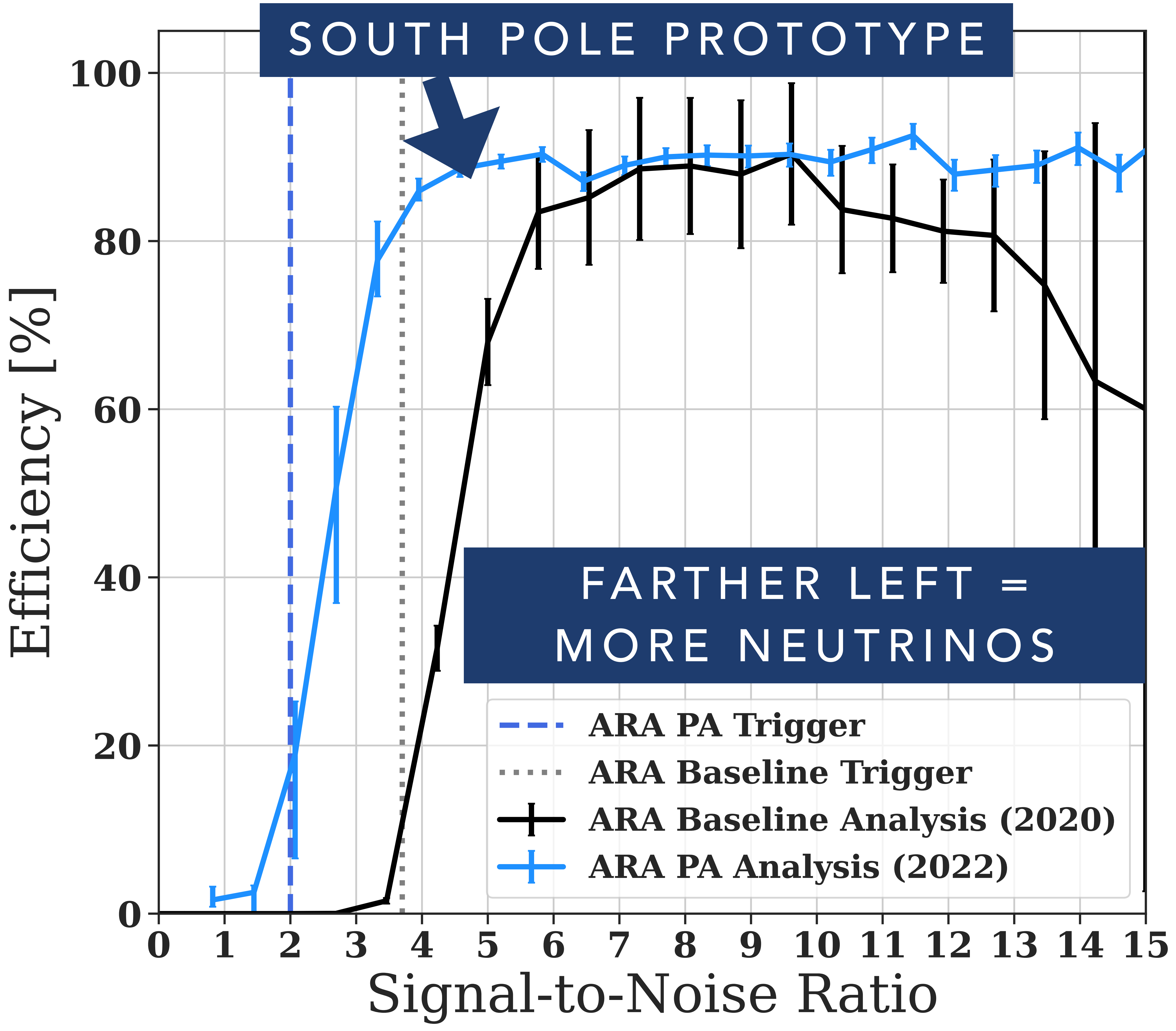

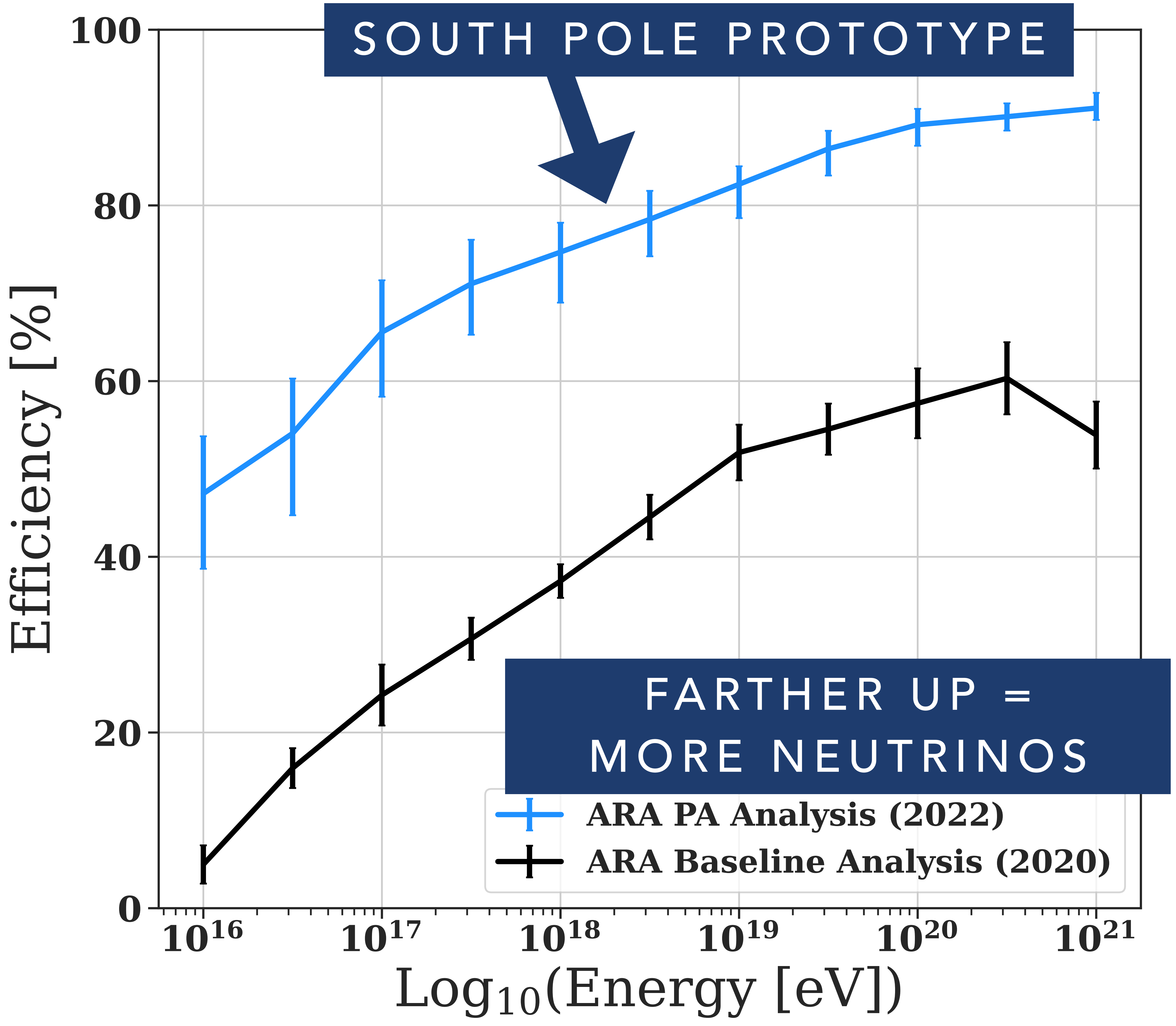

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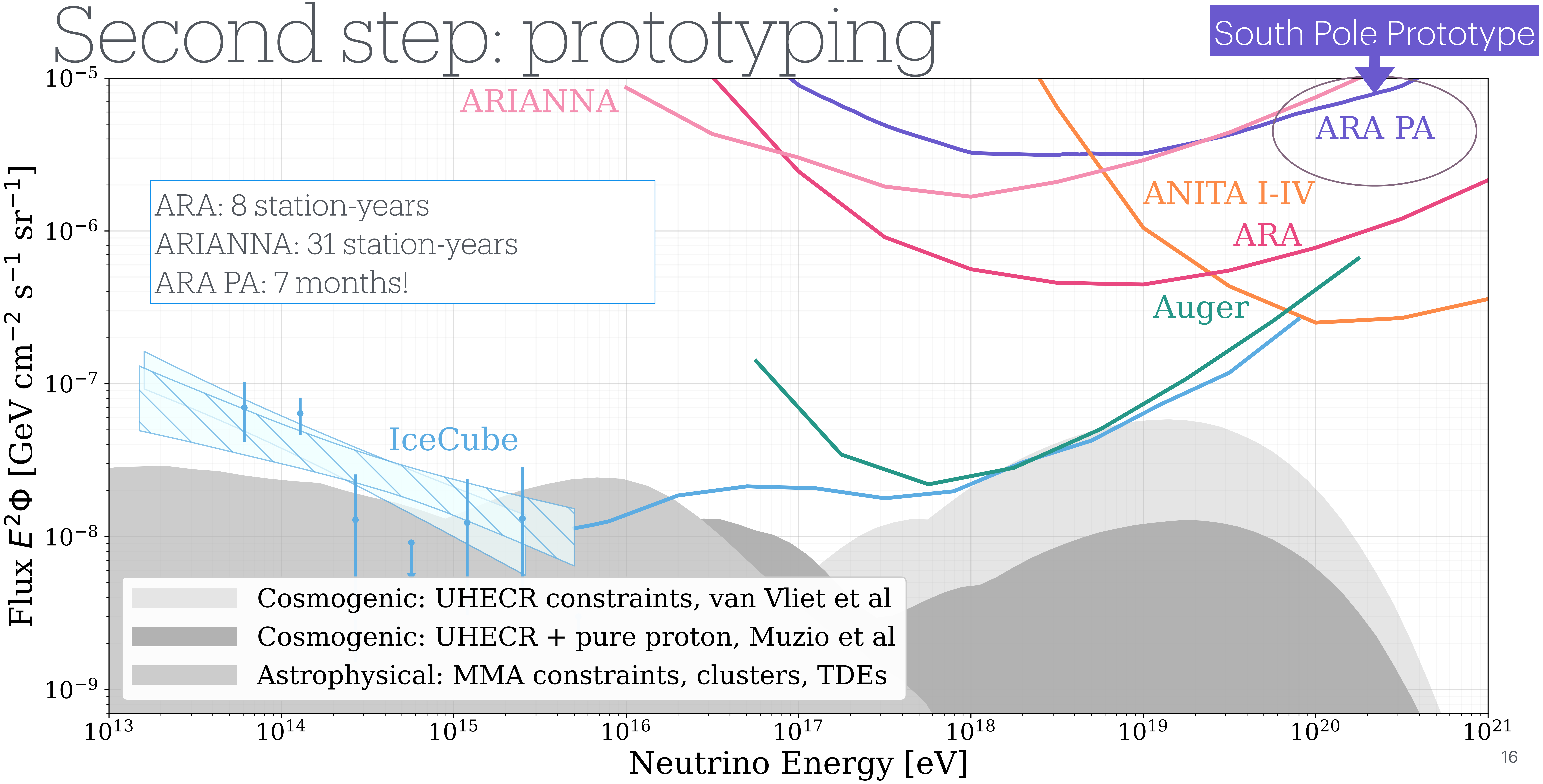


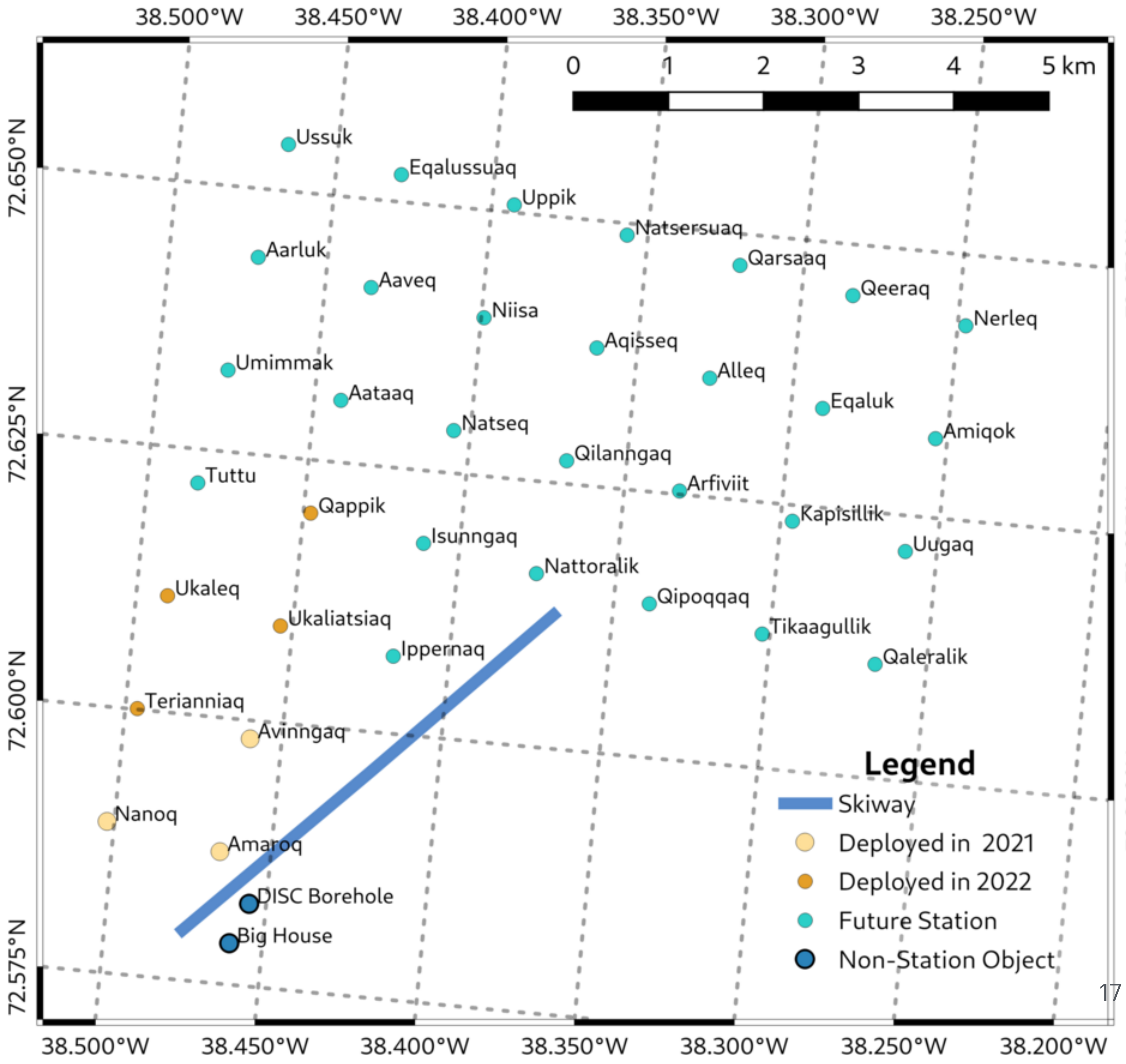
Allison et. al. (PRD 2022)

Second step: prototyping

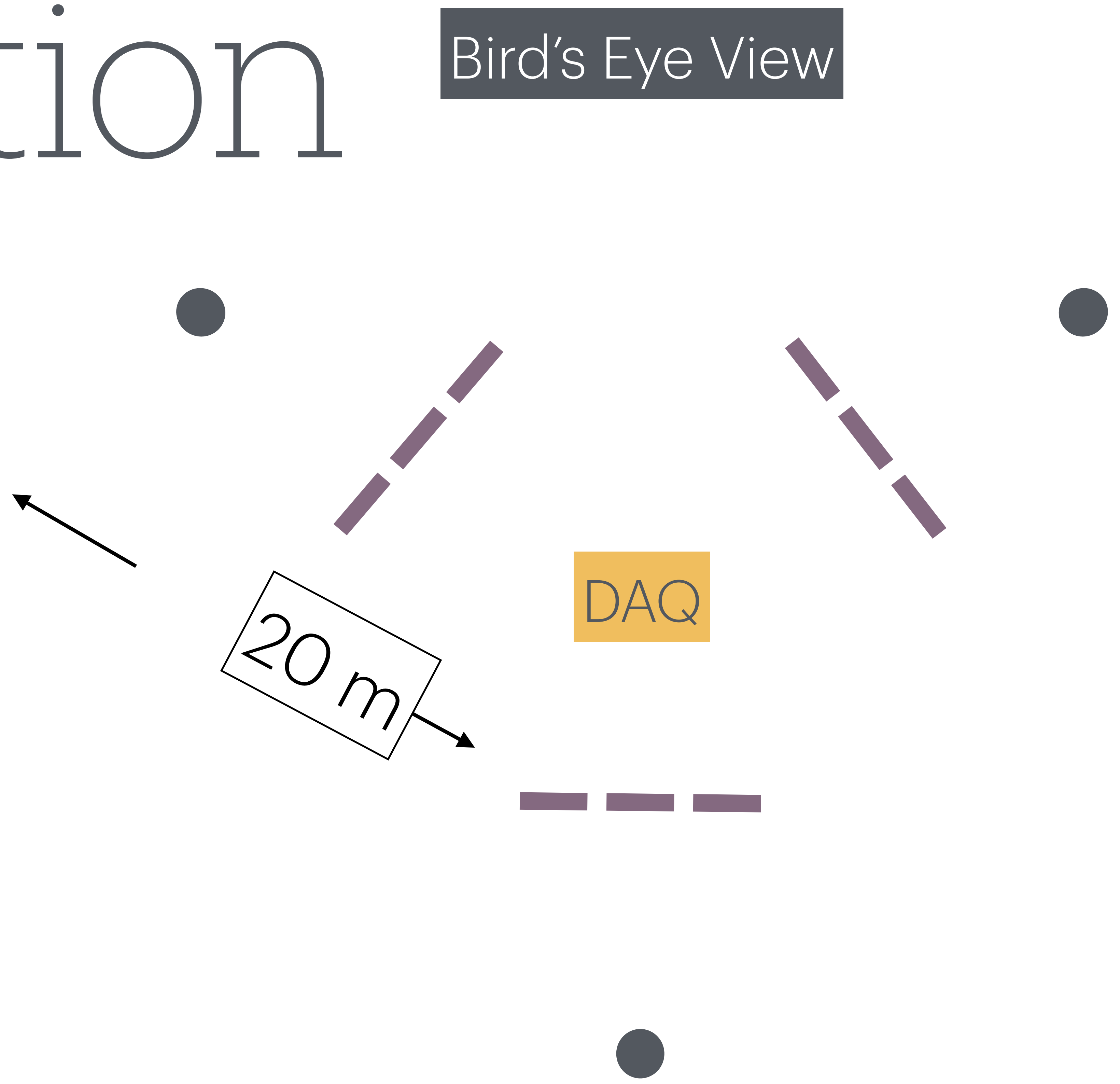
Allison et. al. (PRD 2022)

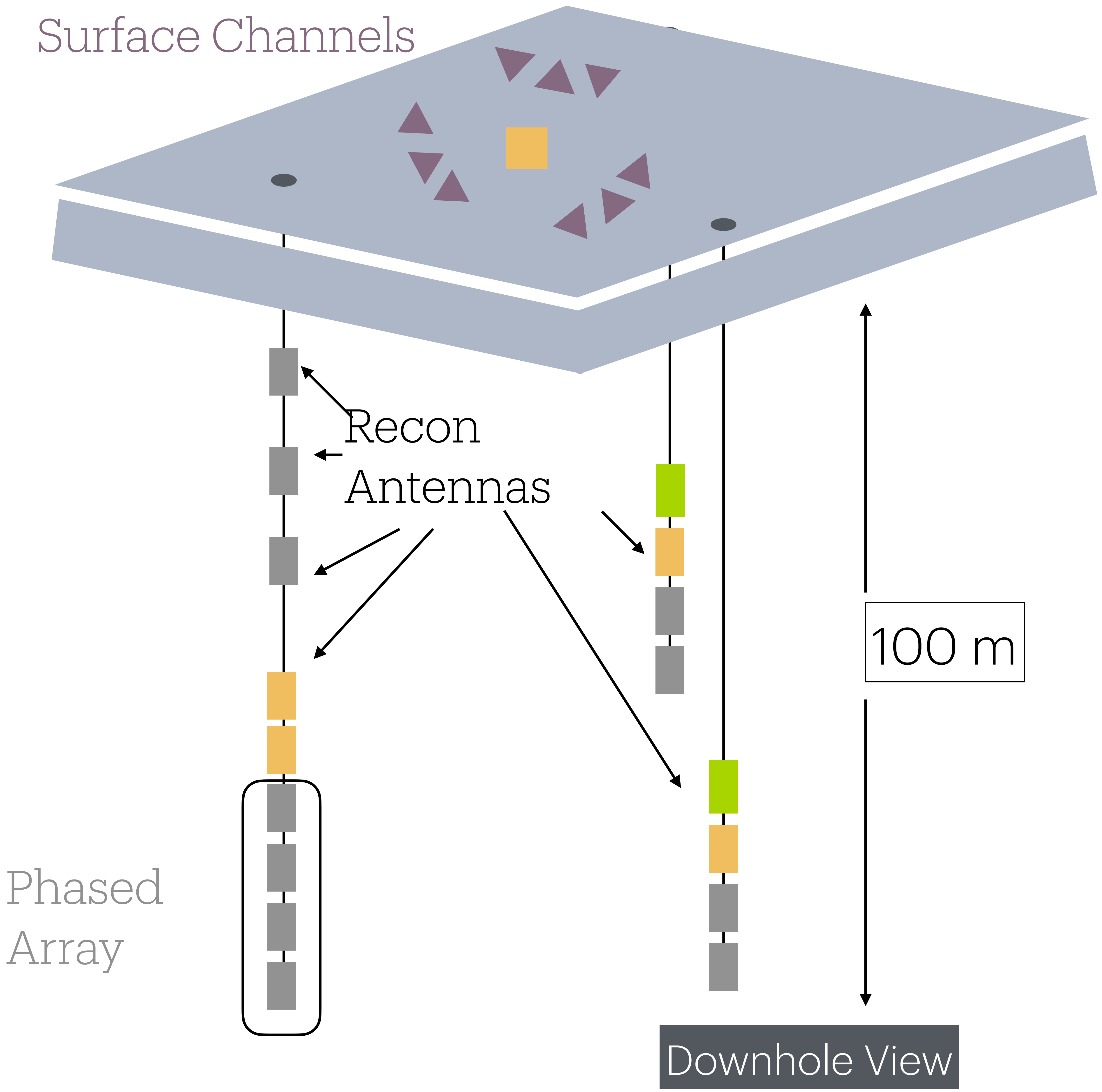
Third Step: try building at scale

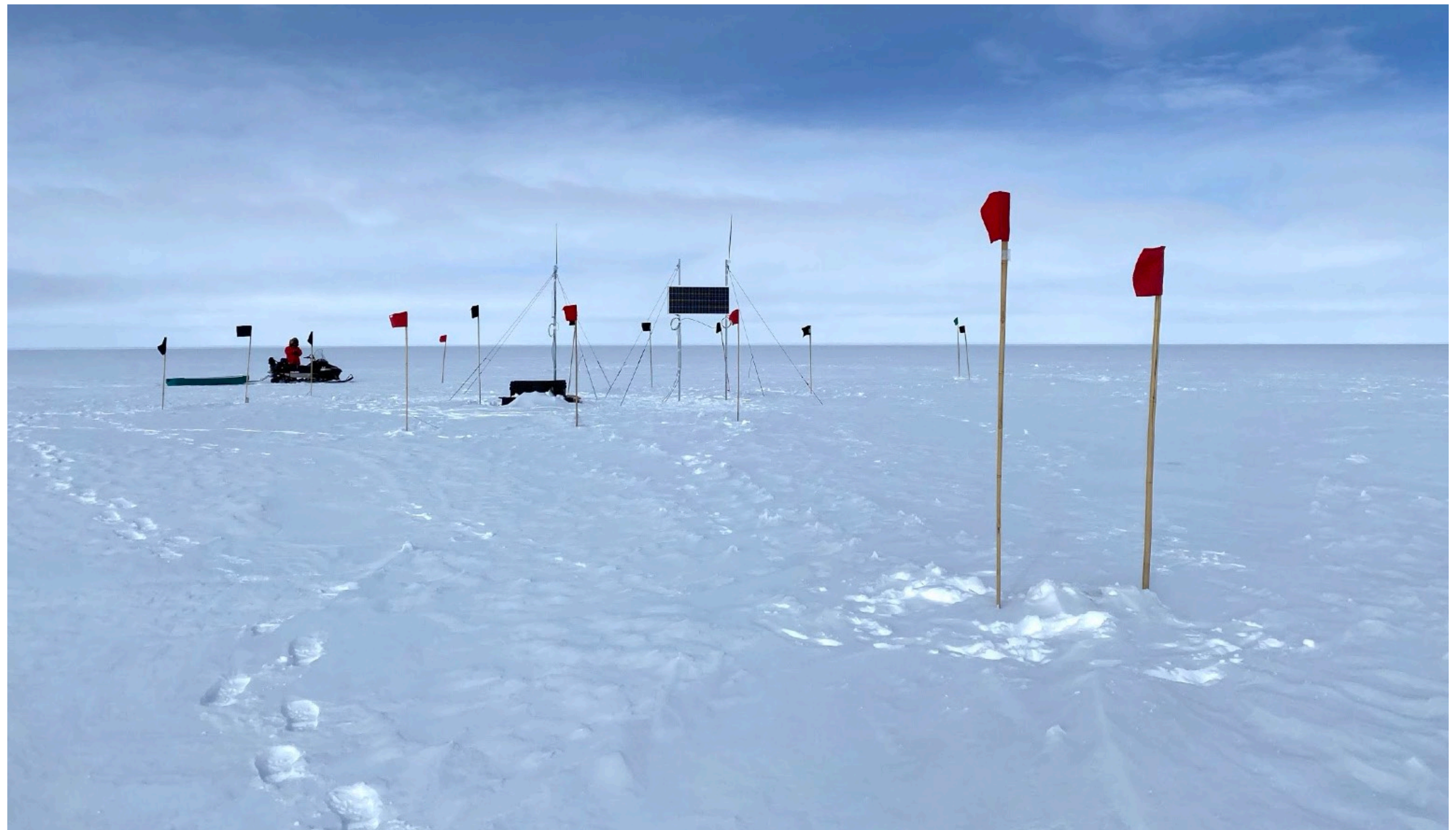
- Need lots of individual phased arrays to accumulate enough livetime to see the very faint neutrino signal
- Enter the Radio Neutrino Observatory in Greenland (RNO-G): fully funded (!) to reach 35(+) stations
- Three stations deployed in 2021 and four deployed in 2022: seven total!
- This summer, holes for seven more stations will be drilled



A single RNO-G Station







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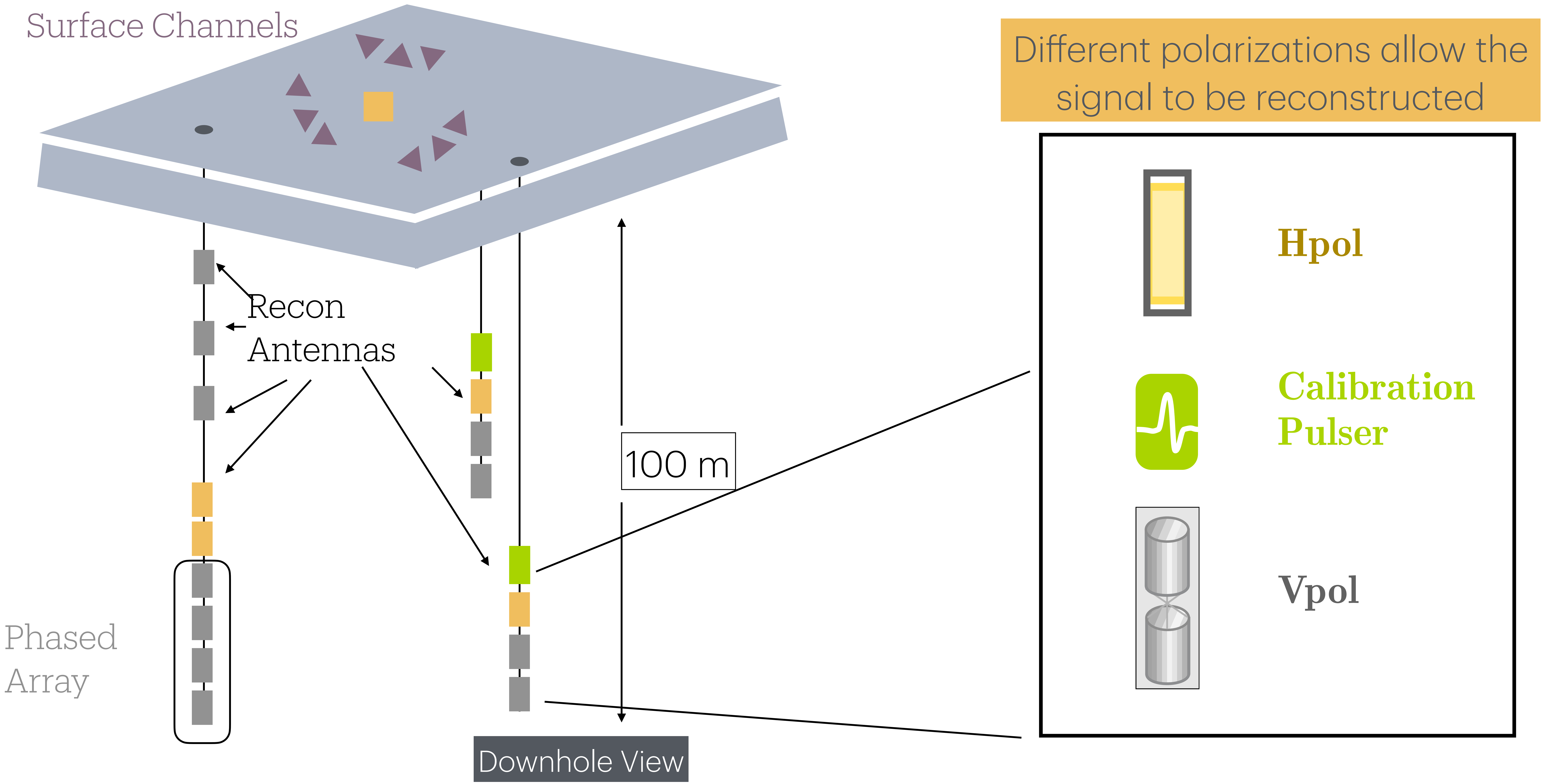

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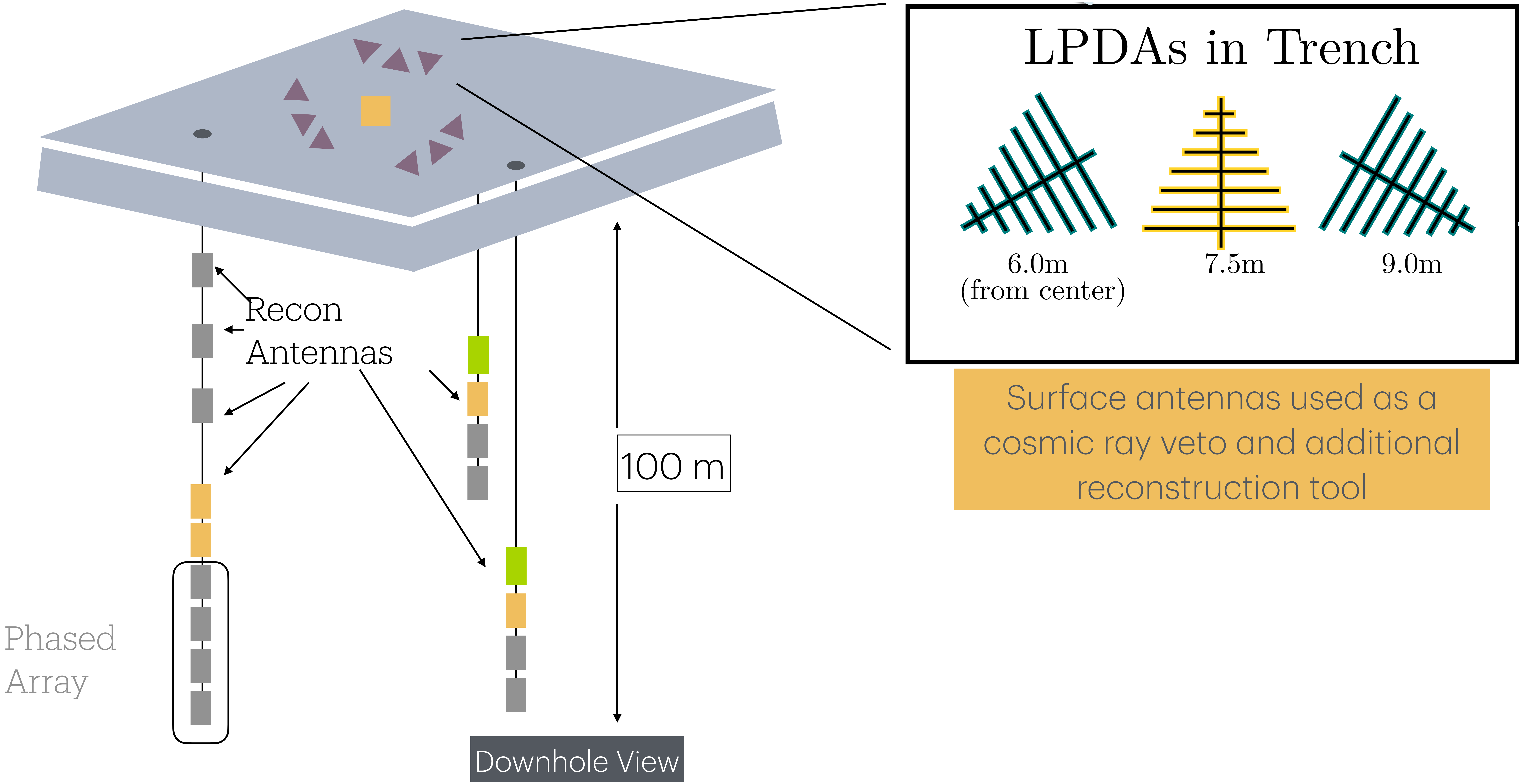
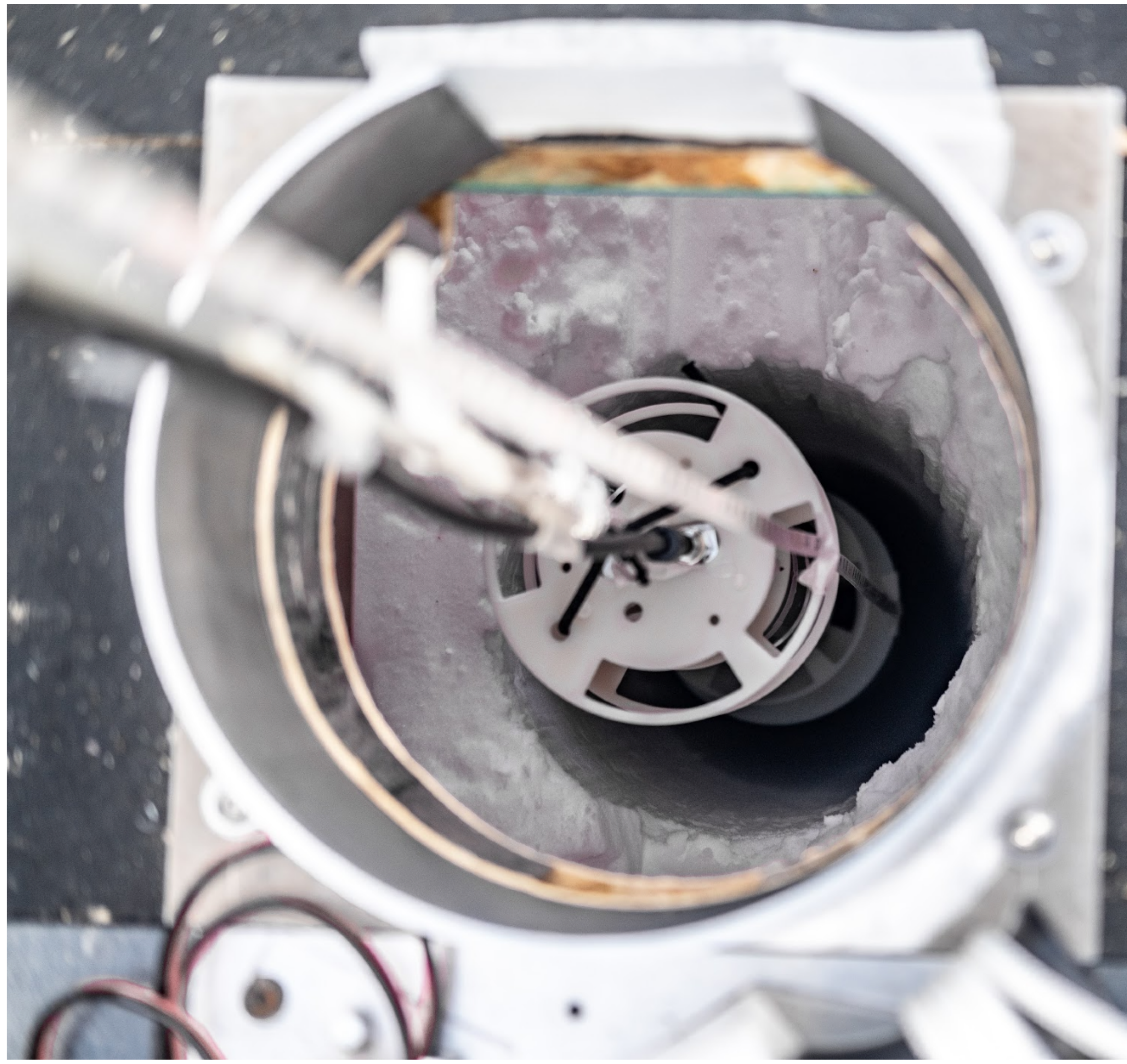


Surface antennas used as a cosmic ray veto and additional reconstruction tool

Antennas in Action!

VPol + LPDA

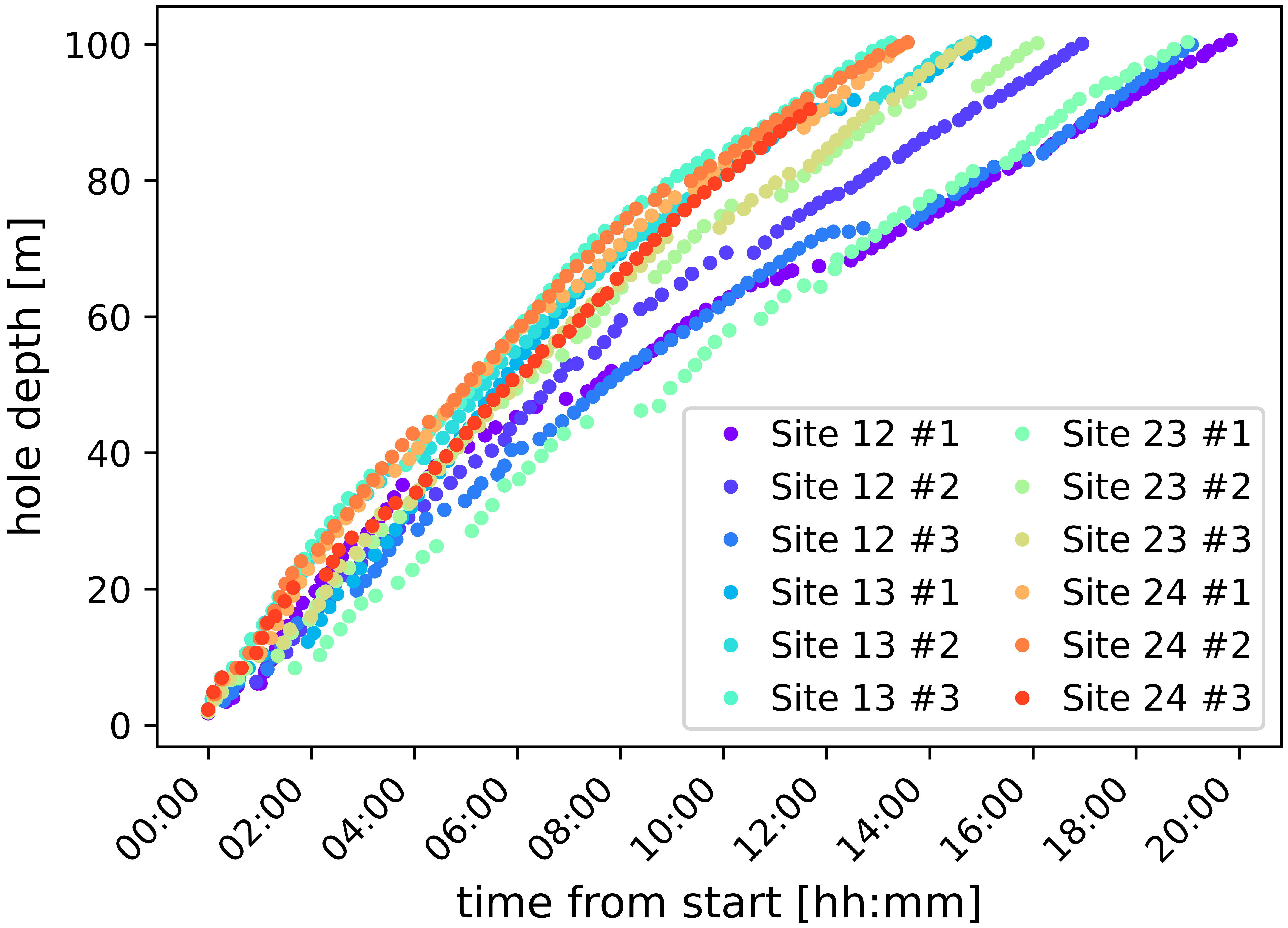
HPol



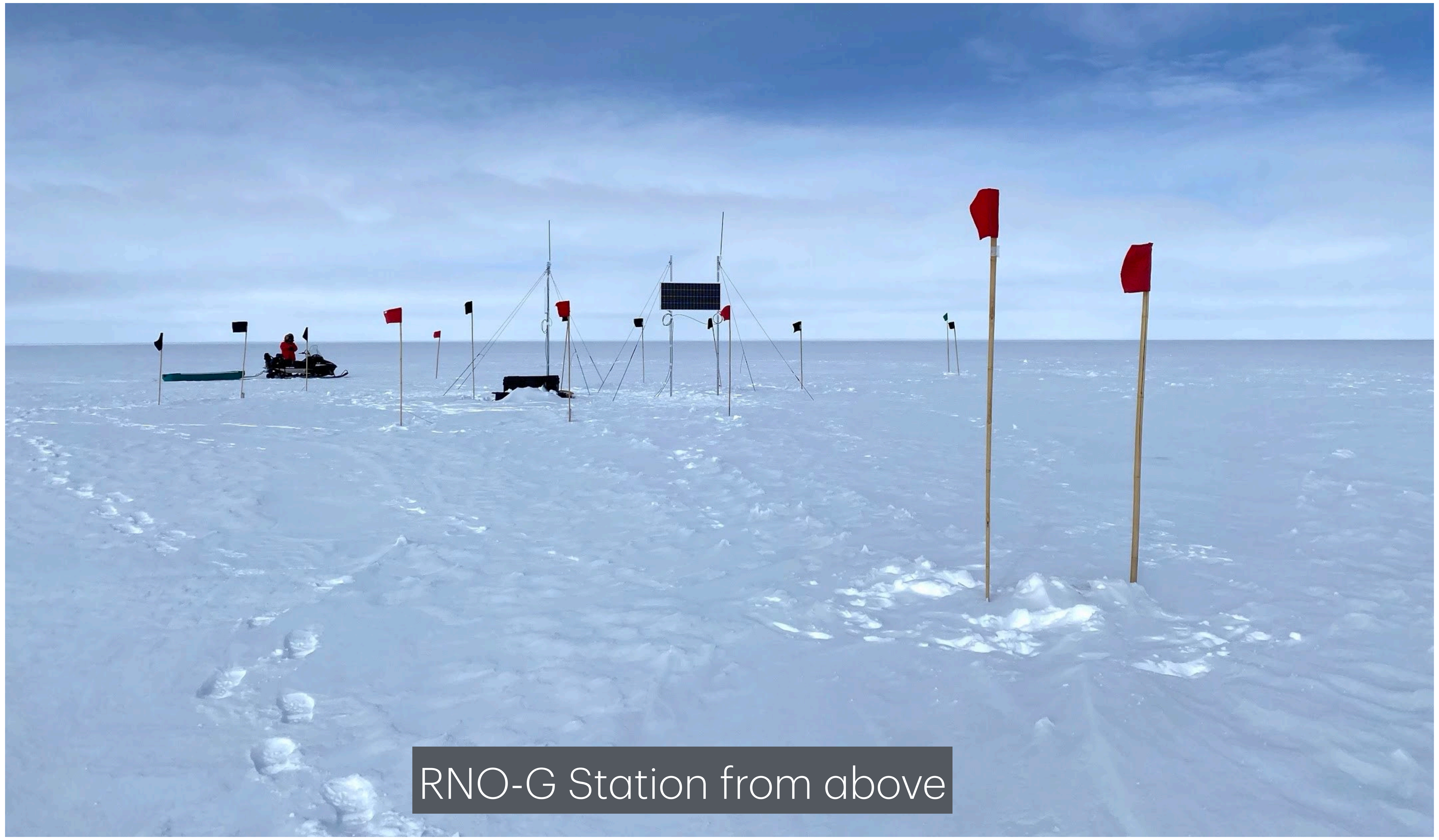
Antenna in deployment hole

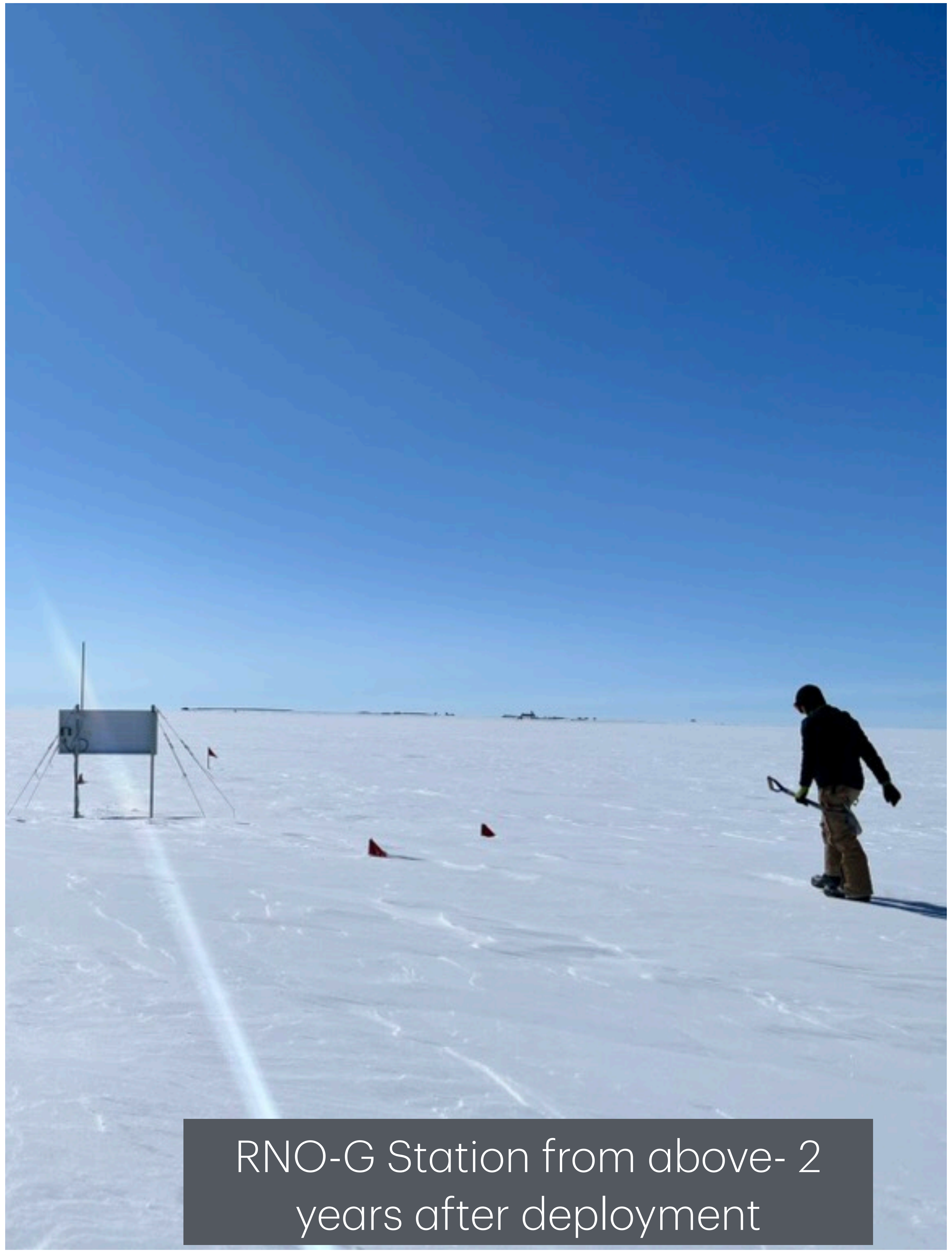
Challenge 1: Drilling

- BigRAID drill: electromechanical, designed specifically for RNO-G
- Drilling holes to 100 m takes time; logistically, it's very hard to drill fast.
- We are getting better at this! Each year, we are improving (and so is the drill)



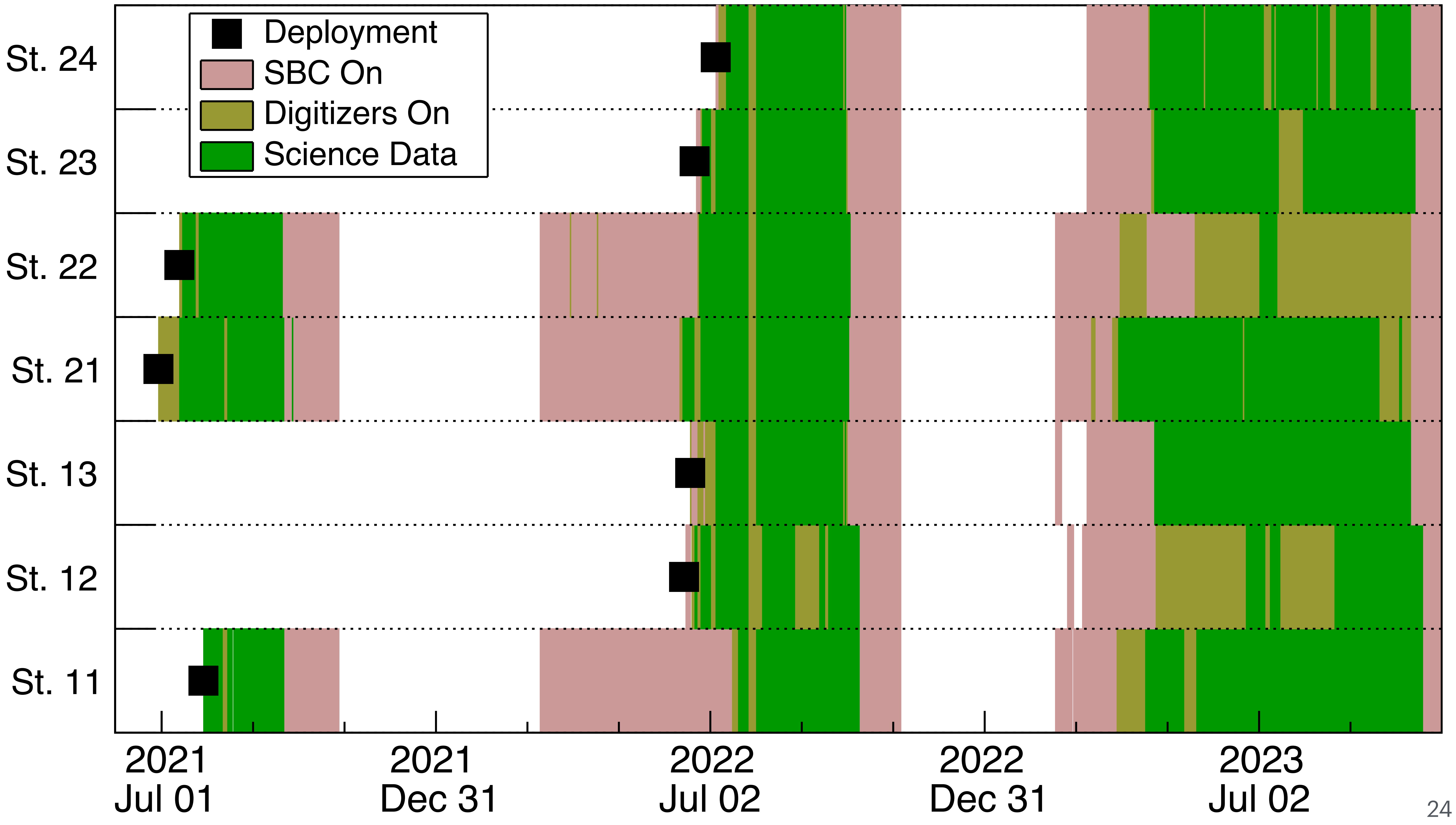
Challenge 2: Snow accumulation


RNO-G Station from above

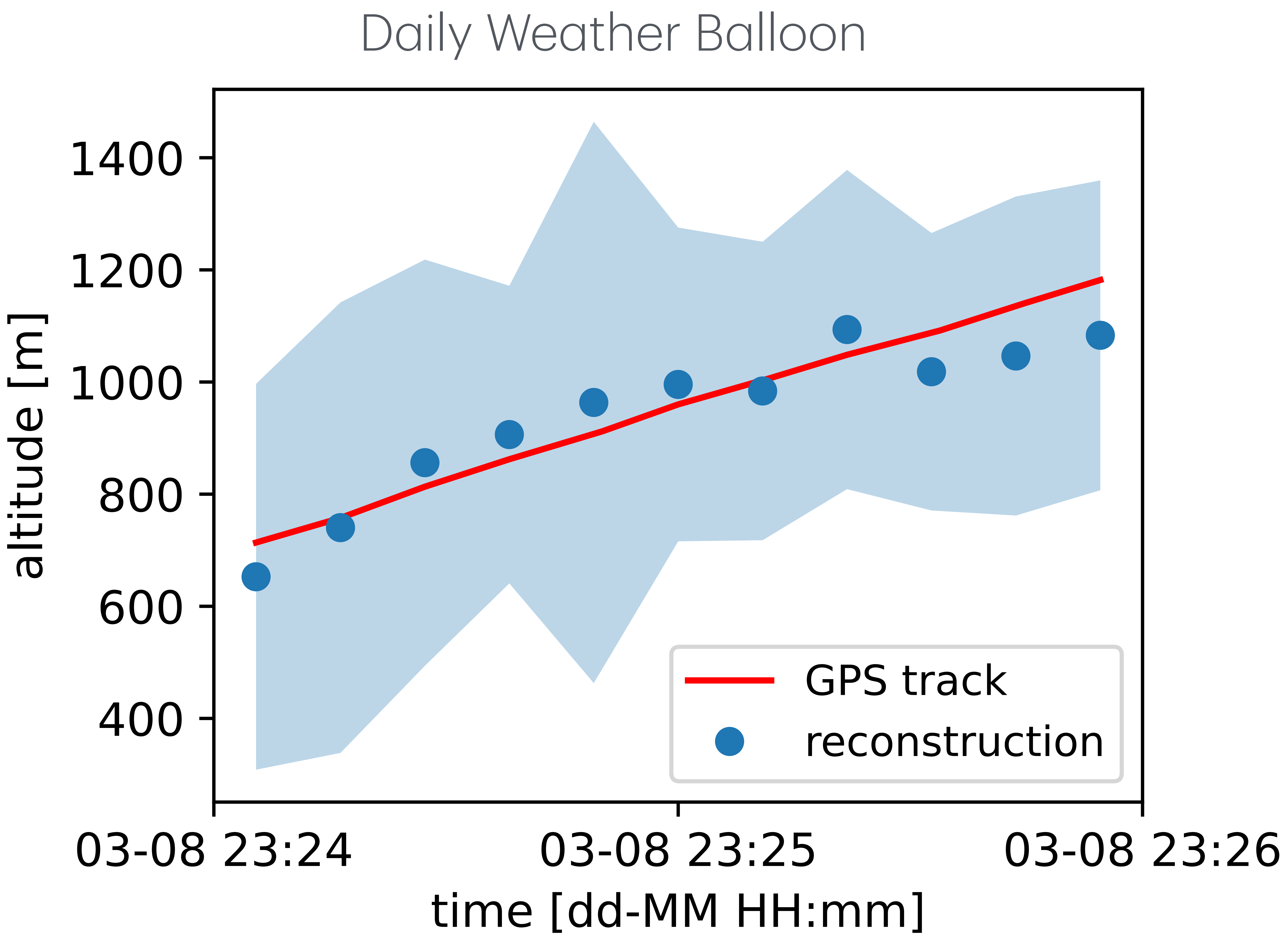

RNO-G Station from above- 2 years after deployment

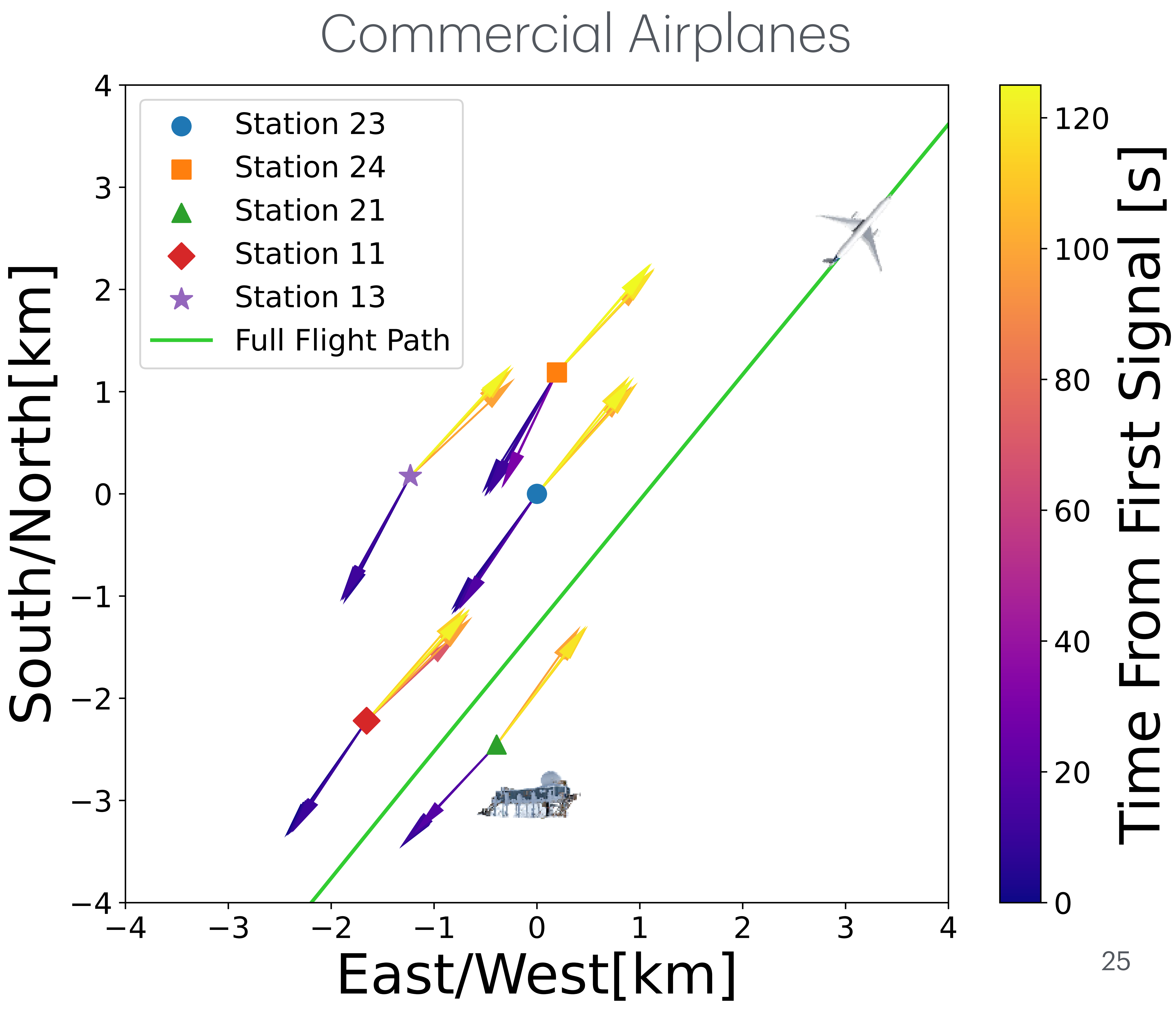
Challenge 3: Daylight

- RNO-G is solar powered- great for building stations many kms from Summit Station
- Downside: can only take data for ~6 months per year
- Wind power is a possible future option



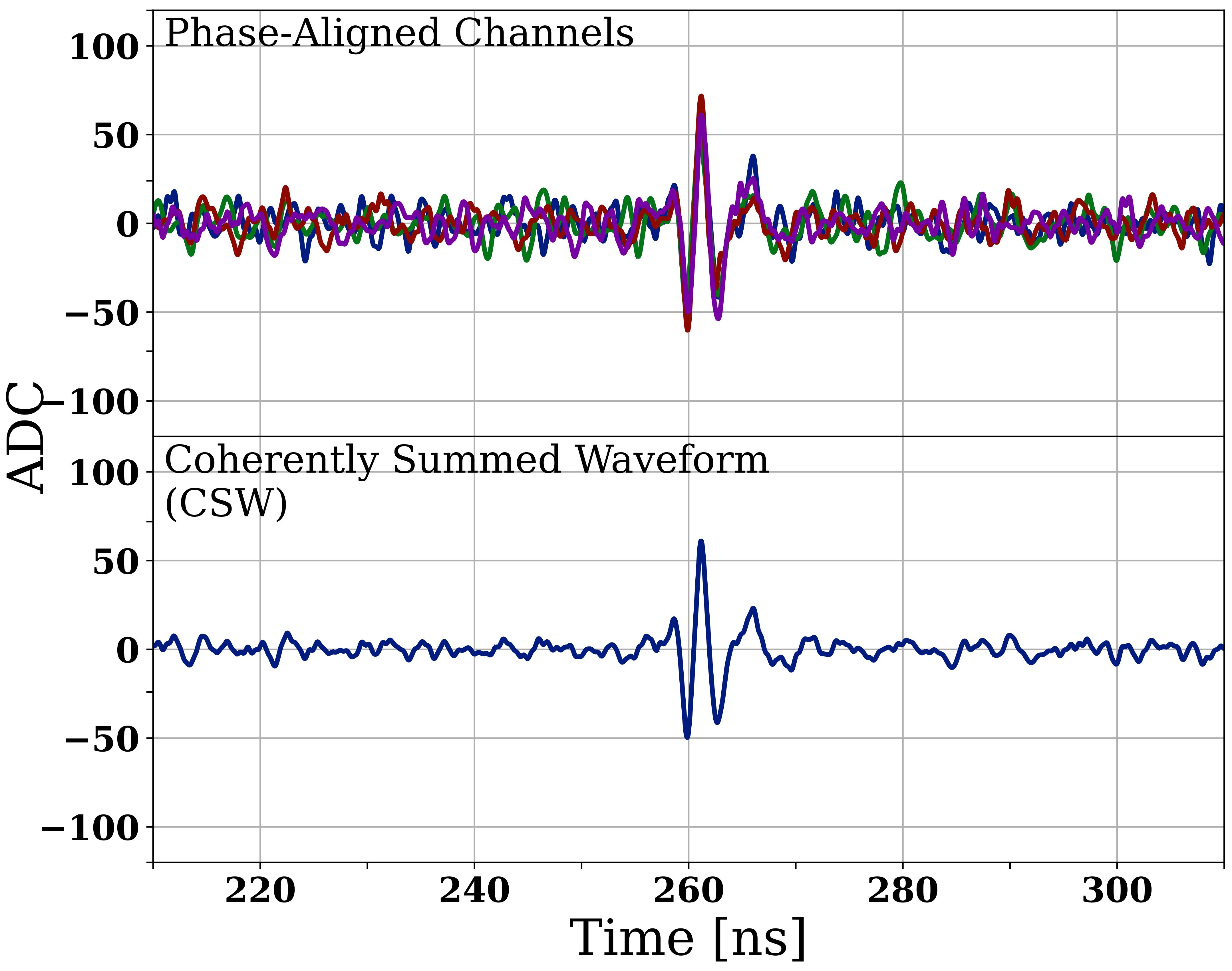
Challenge 4: Human-made noise

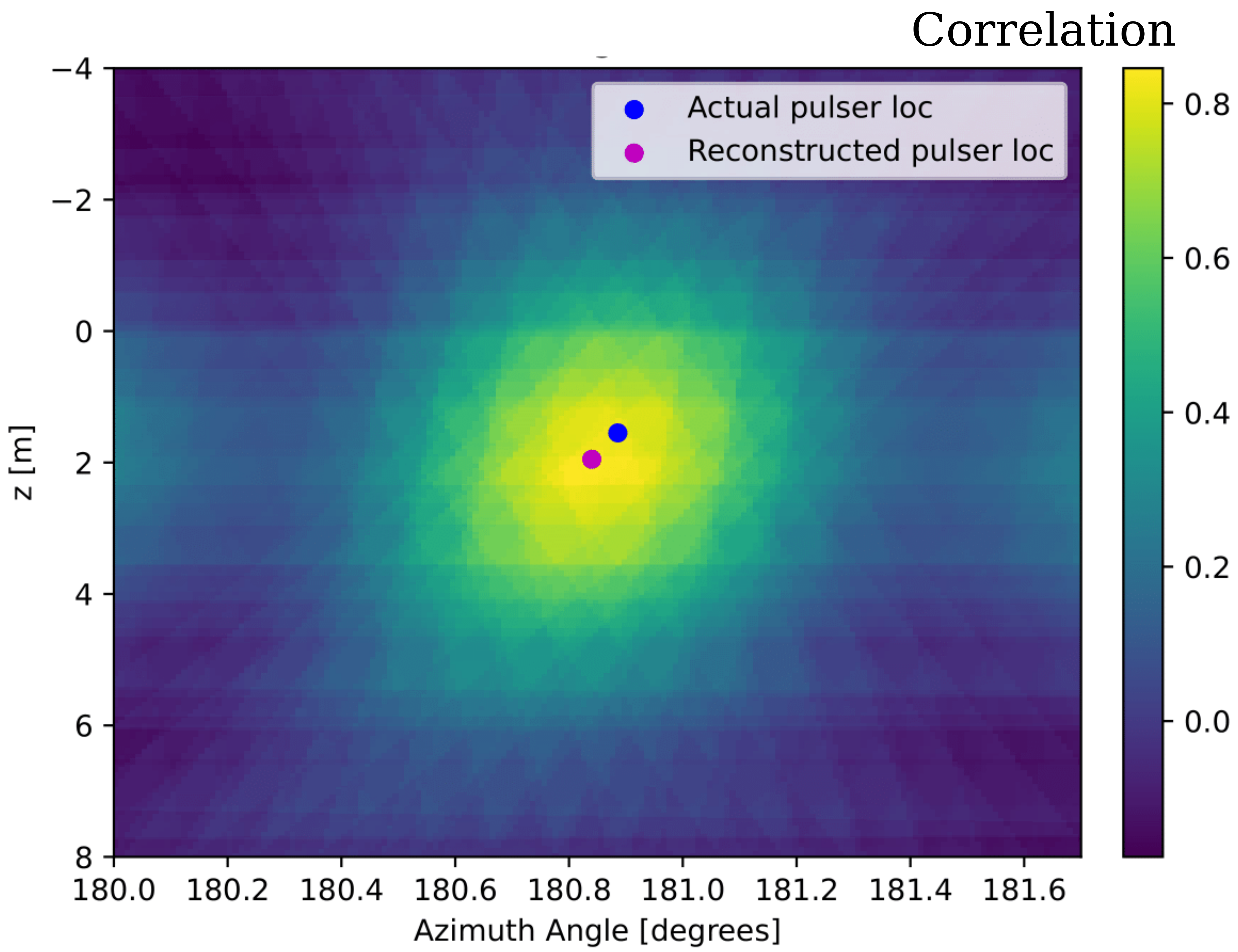




Challenge 5: Calibration

Need < 5 cm error on antenna locations- and a good ice model!





Building towards the future

- RNO-G is currently being constructed and is carefully building tools needed to conduct a neutrino search
- Currently using cosmic rays to determine instrument performance
- Lots of advancements have been needed to make this happen, on every front: drilling, antenna design, hardware/firmware, and calibration
- 35 stations + 5 years of data will make RNO-G sensitive to most optimistic cosmogenic flux models