

# ASTROPHYSICAL NEUTRINOS: RADIO-BASED EXPERIMENTS



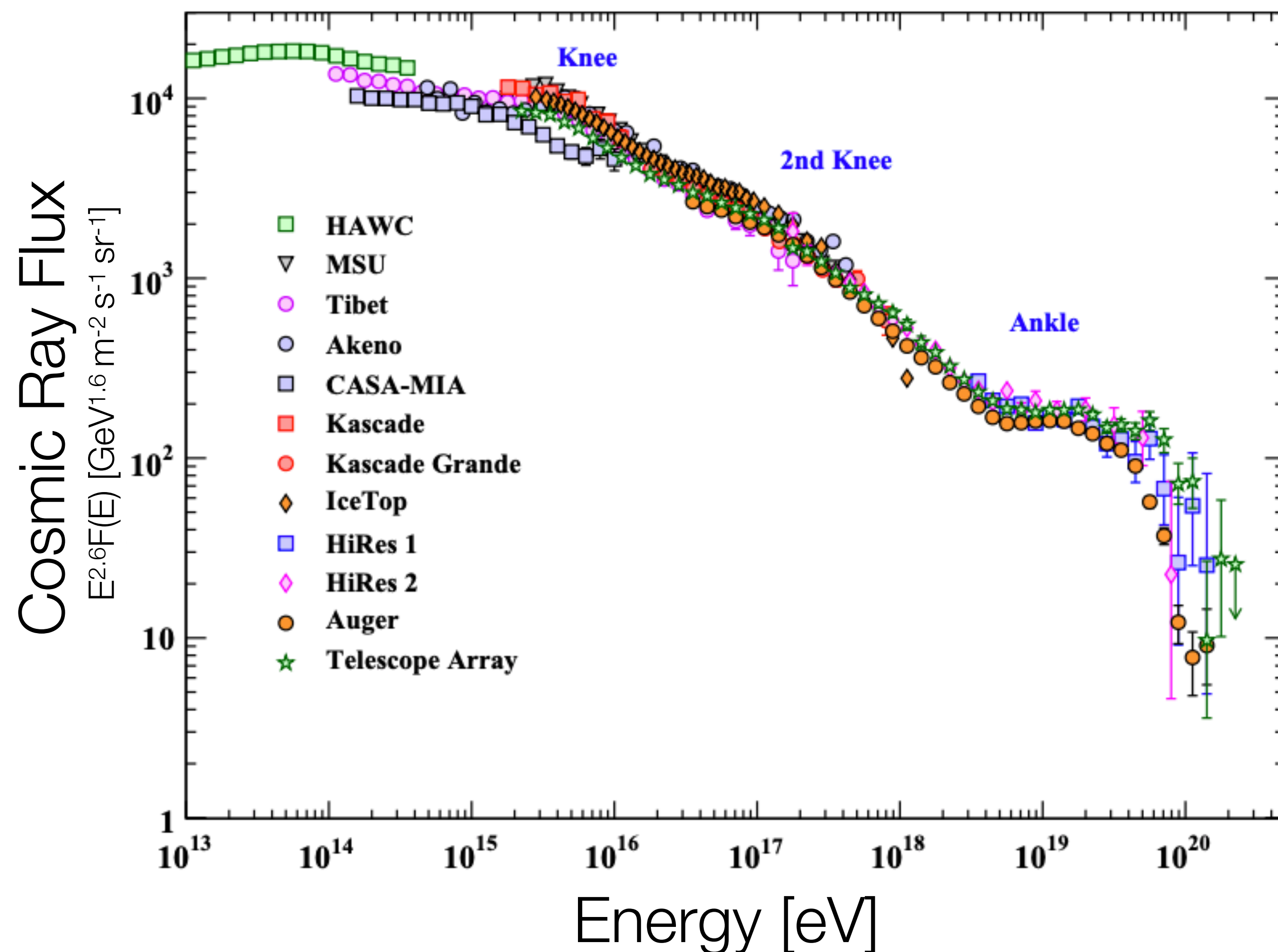
Kaeli Hughes  
Assistant Professor  
The Ohio State University



Neutrino 2024  
June 19, 2024



# THE COSMIC RAY MYSTERY

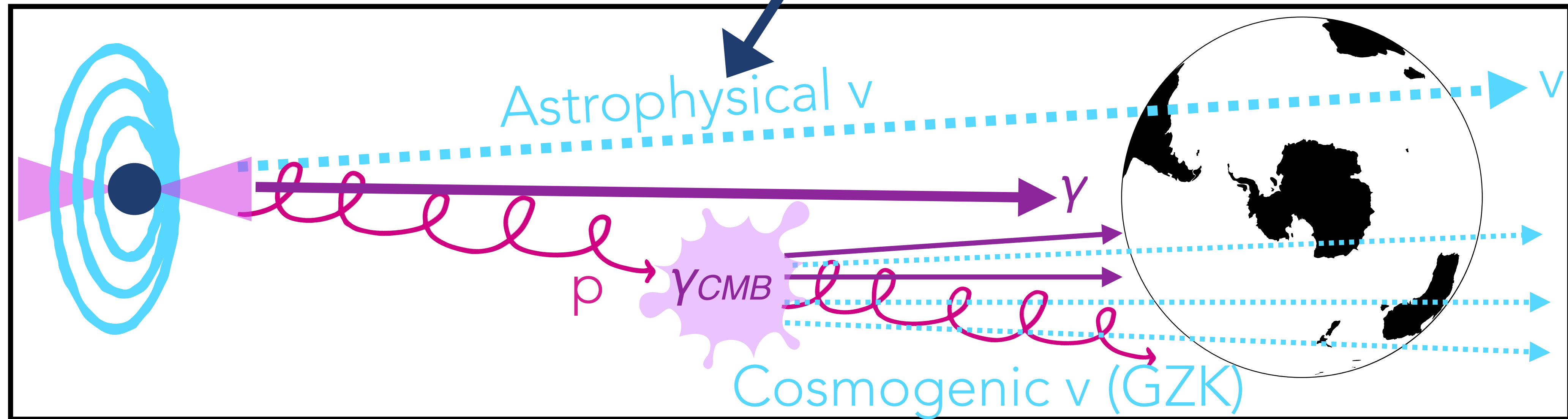


**Where are the highest energy cosmic rays coming from?**

- **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?

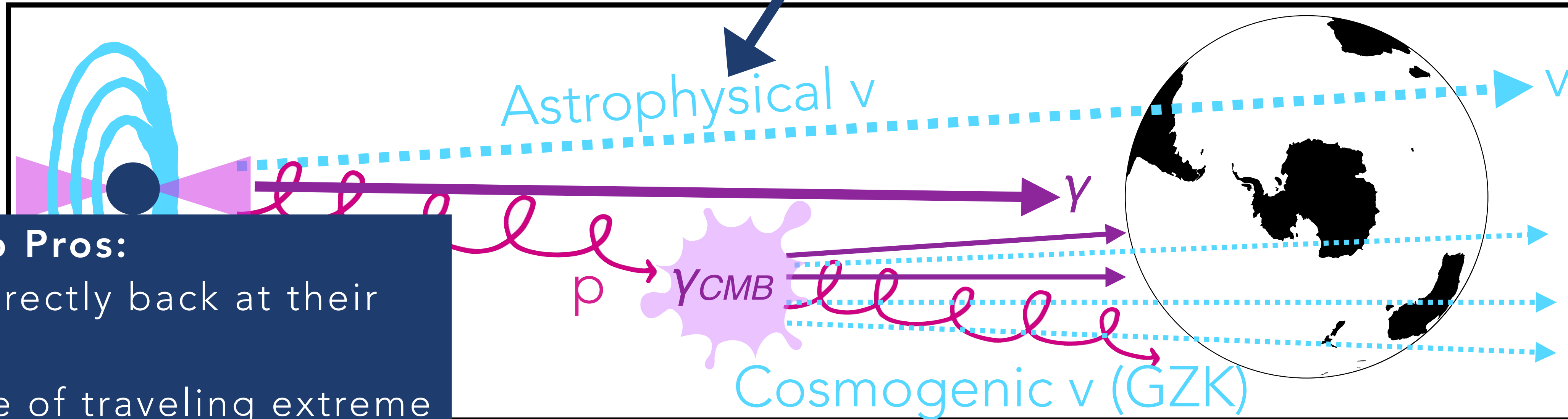
Produced from ultra-high energy sources via cosmic ray interactions (p-p, p- $\gamma$ )



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

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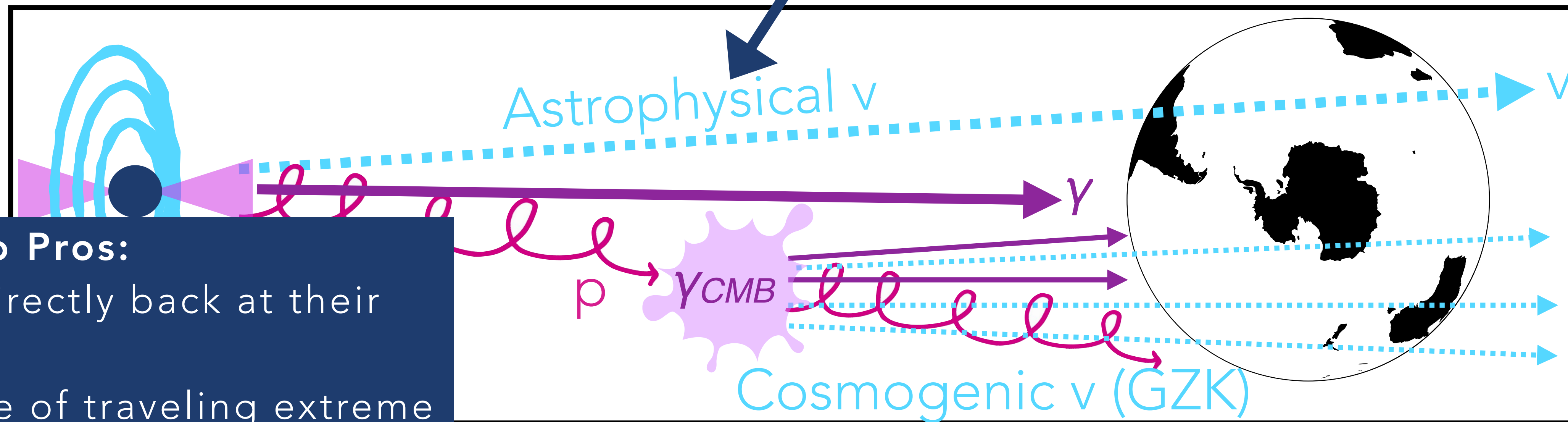
**Neutrino Pros:**

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

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

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Produced from ultra-high energy sources via cosmic ray interactions (p-p, p- $\gamma$ )



## Neutrino Pros:

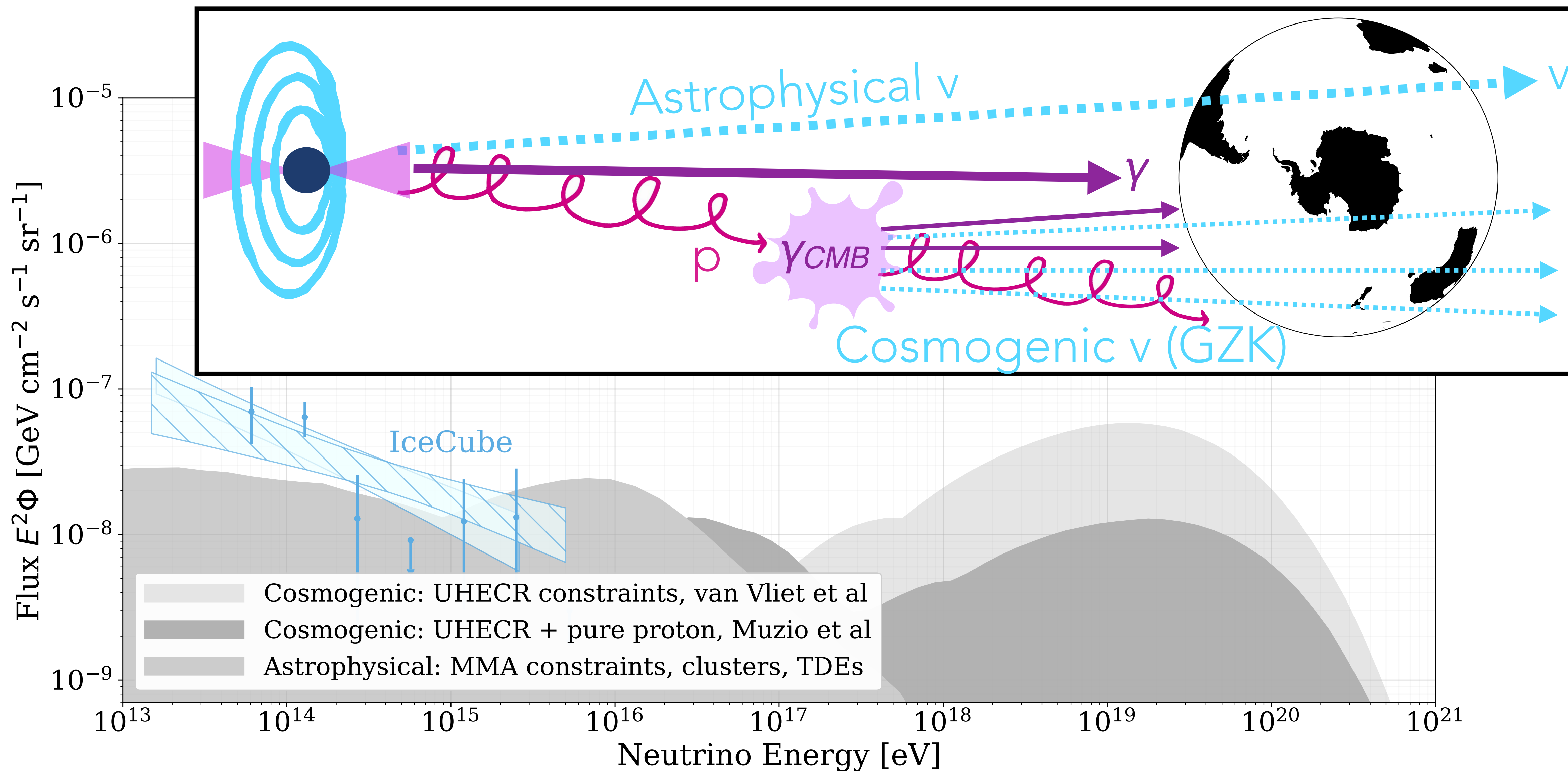
- Point directly back at their sources
- Capable of traveling extreme distances without interacting

## Neutrino Cons:

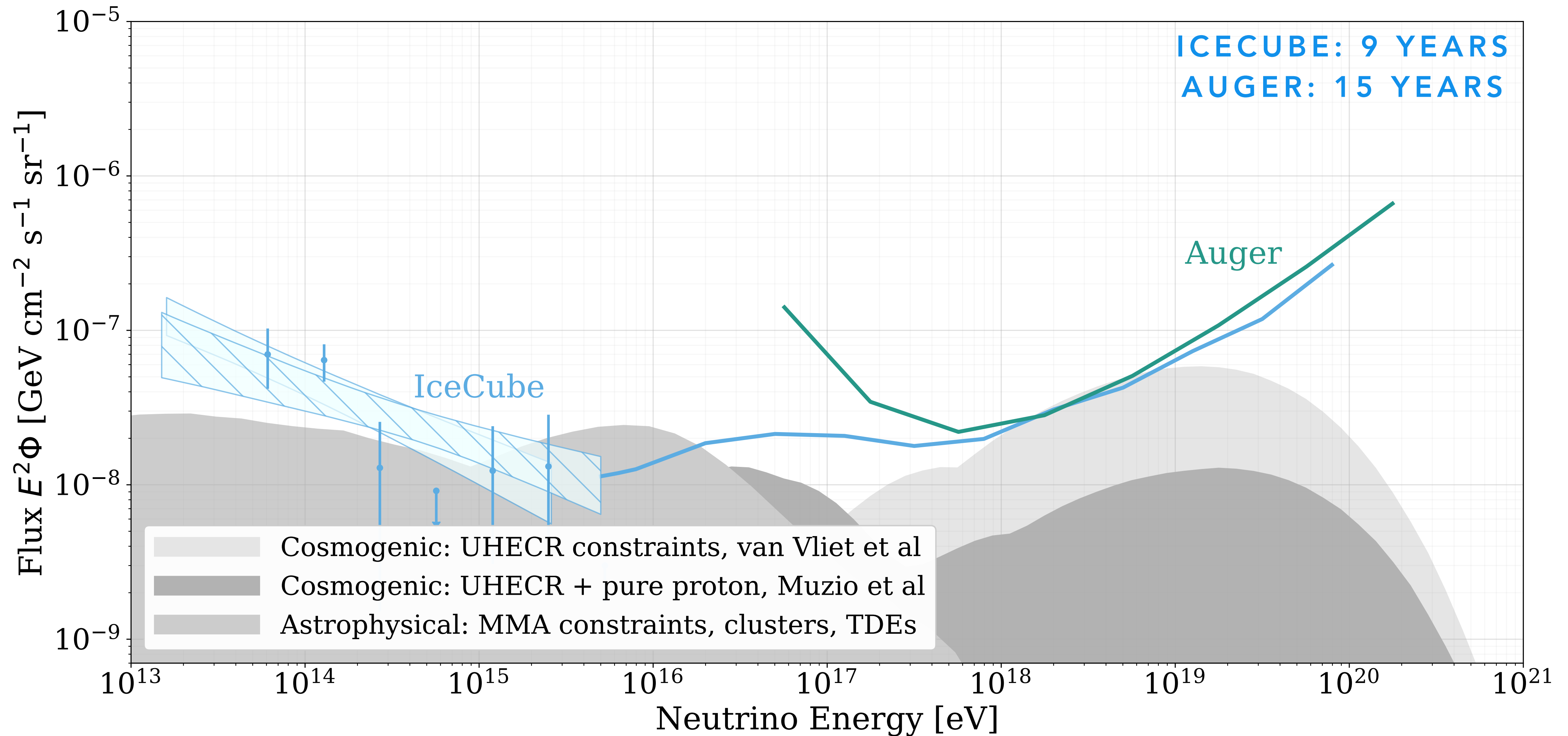
- Capable of traveling straight through the Earth without interacting

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

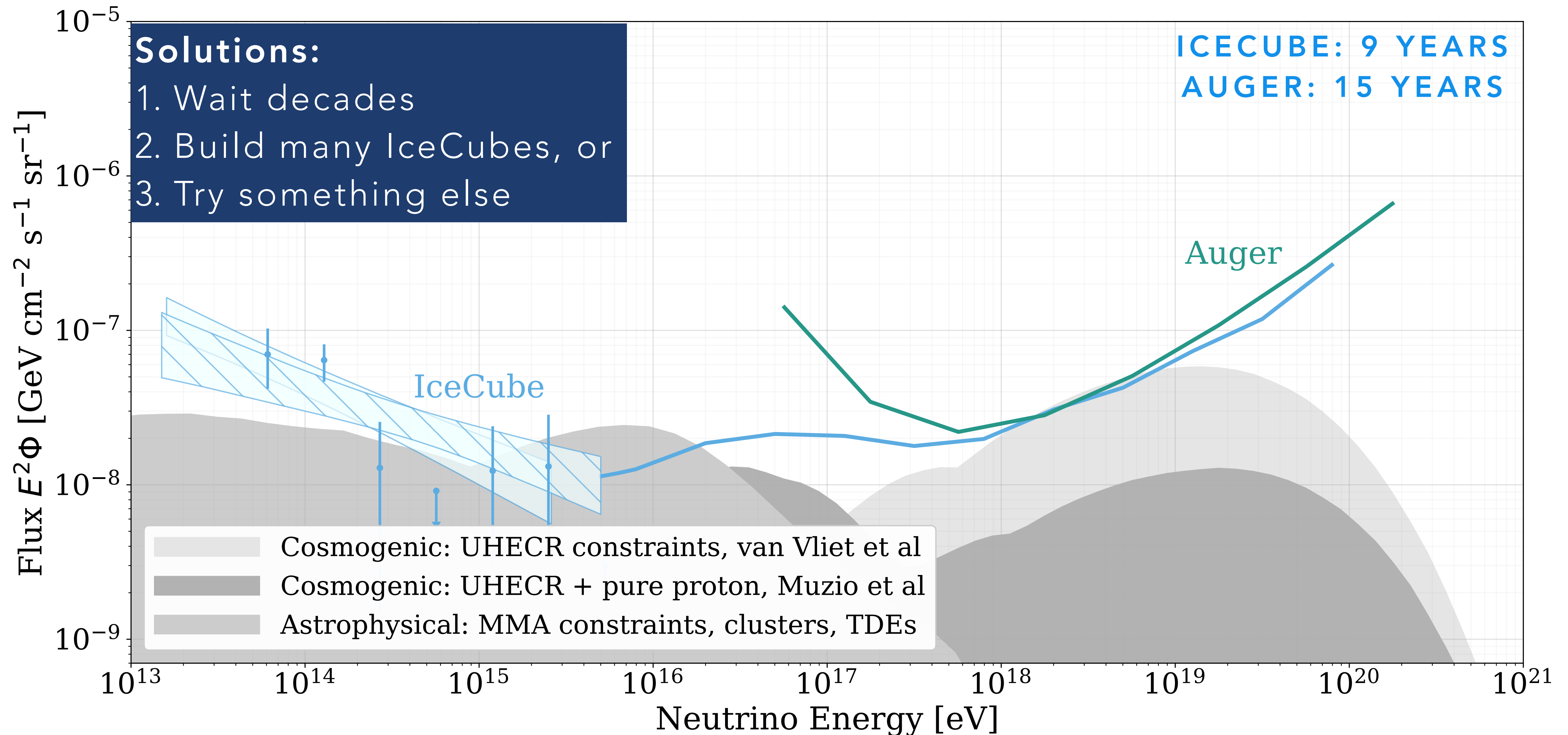
# NEUTRINOS ARE EXPECTED AT HIGHER ENERGIES



# WE NEED NEW STRATEGIES TO LOOK AT HIGHER ENERGIES



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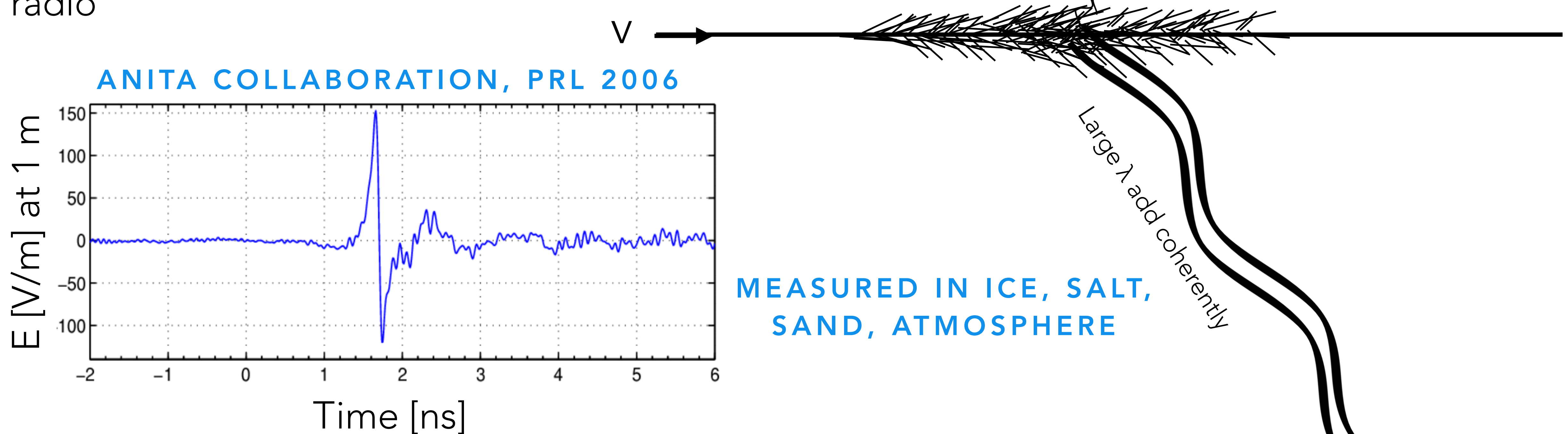




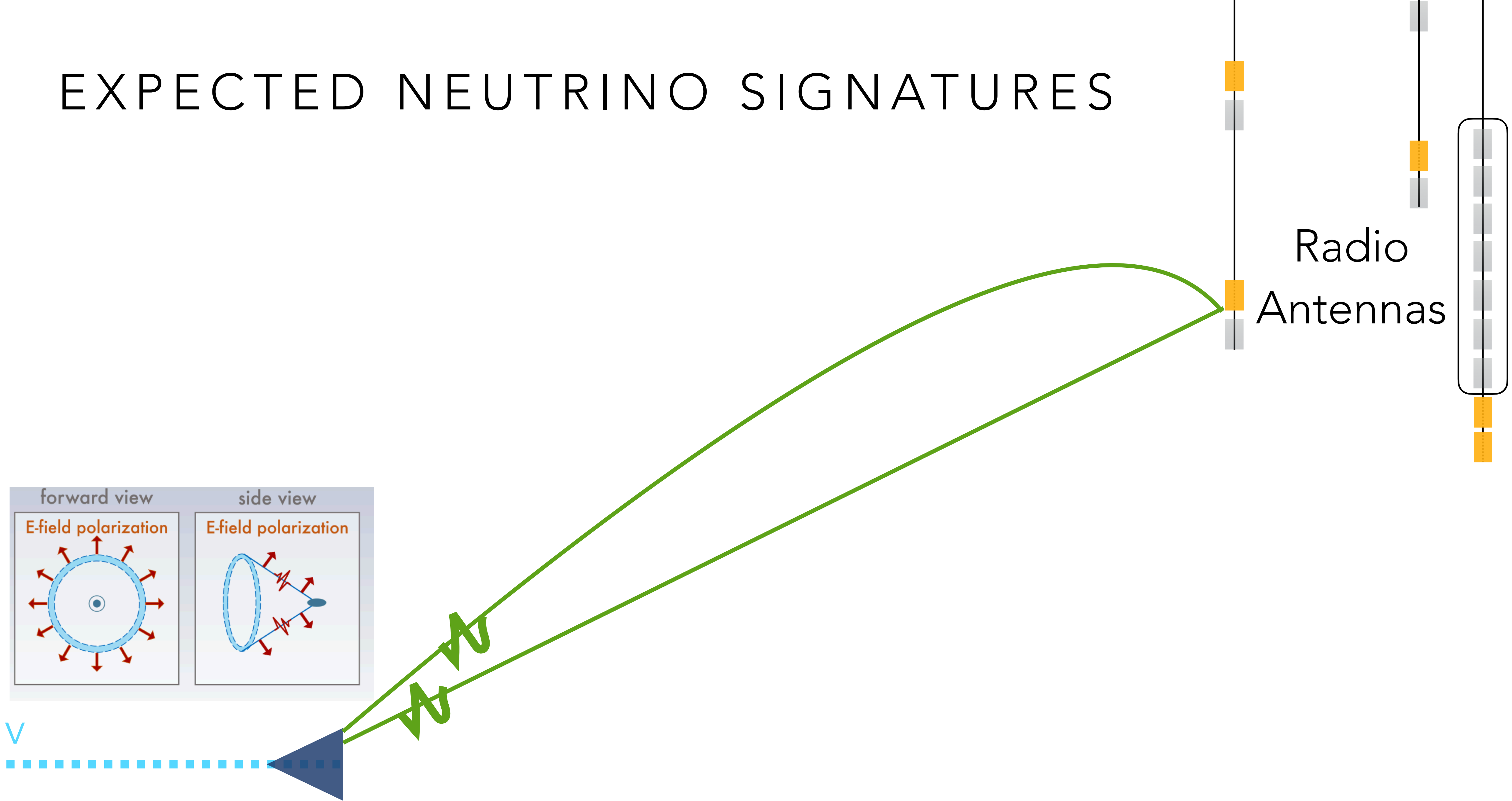
# INSTEAD OF OPTICAL, TRY RADIO

## 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



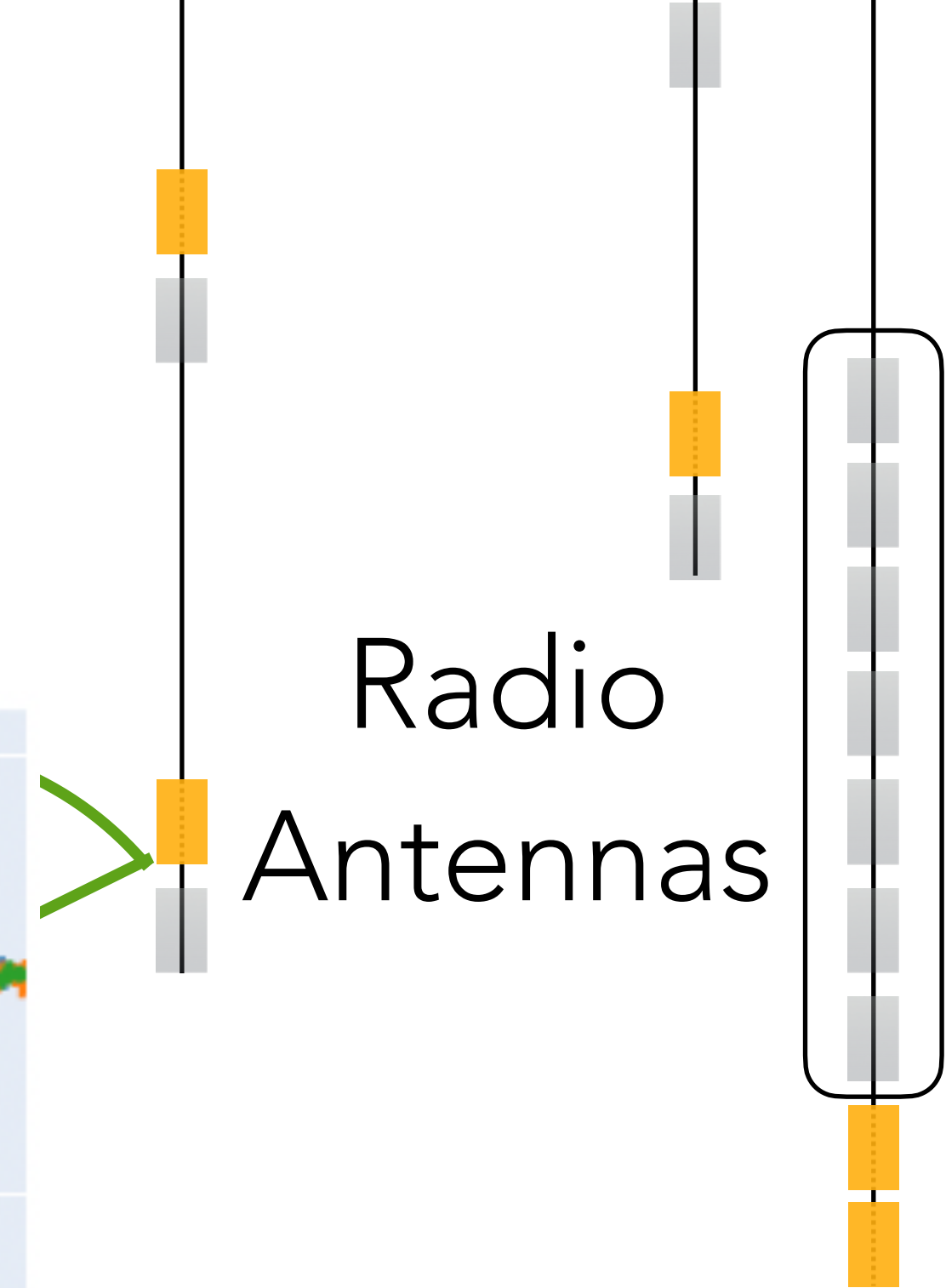
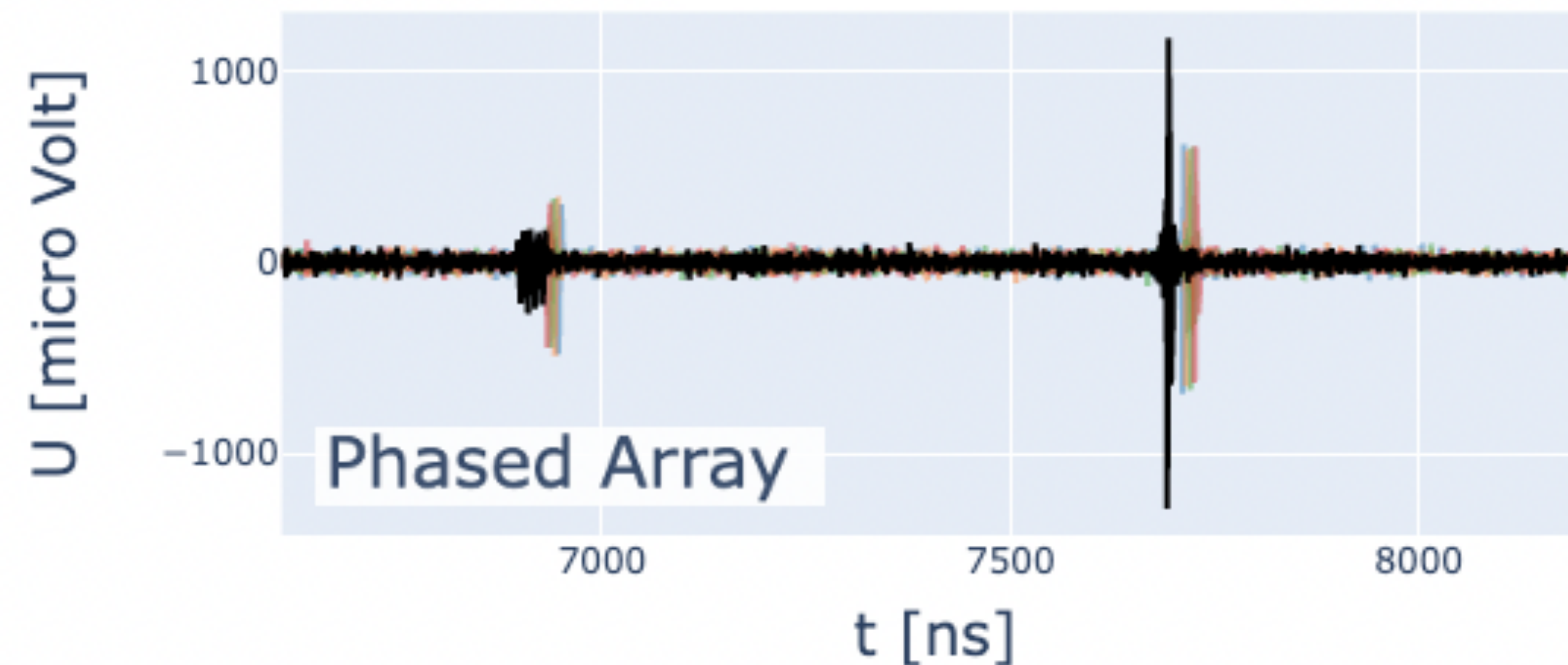
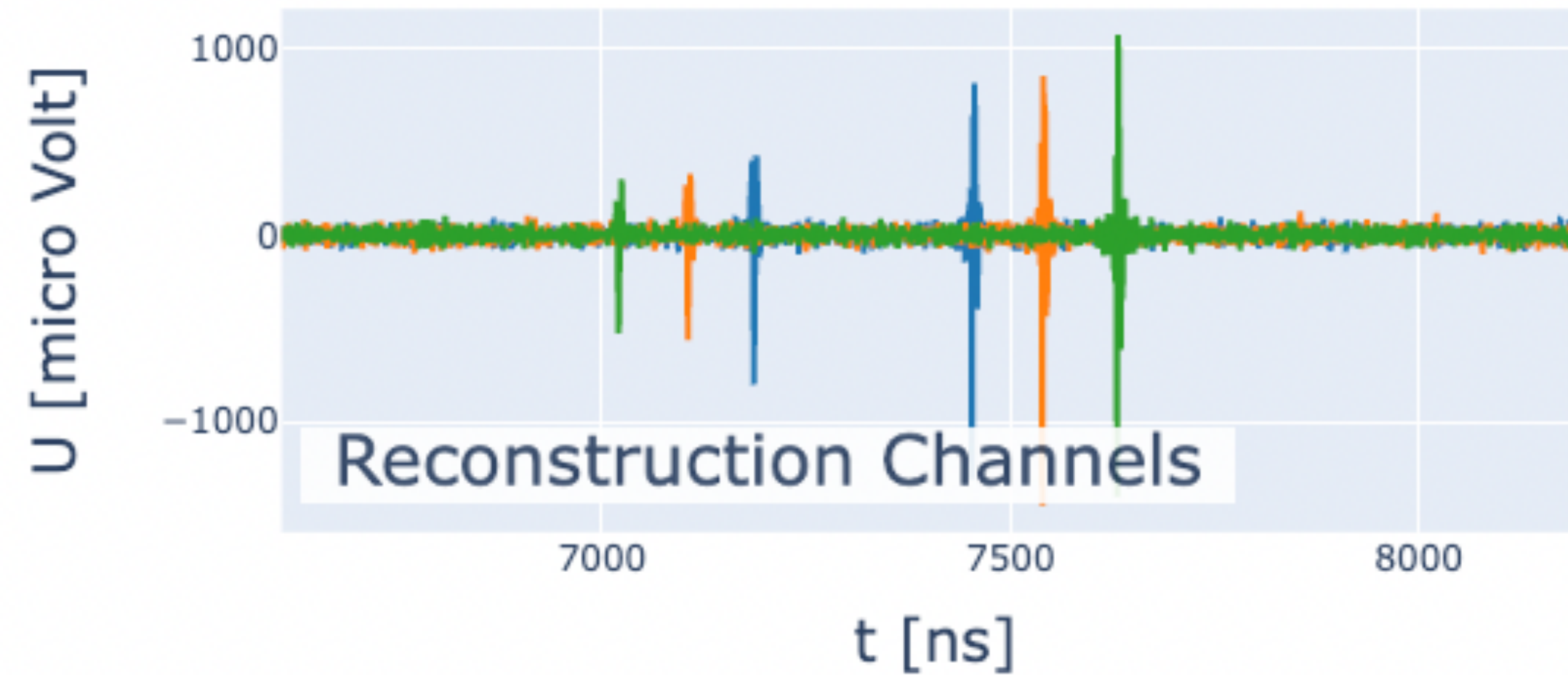
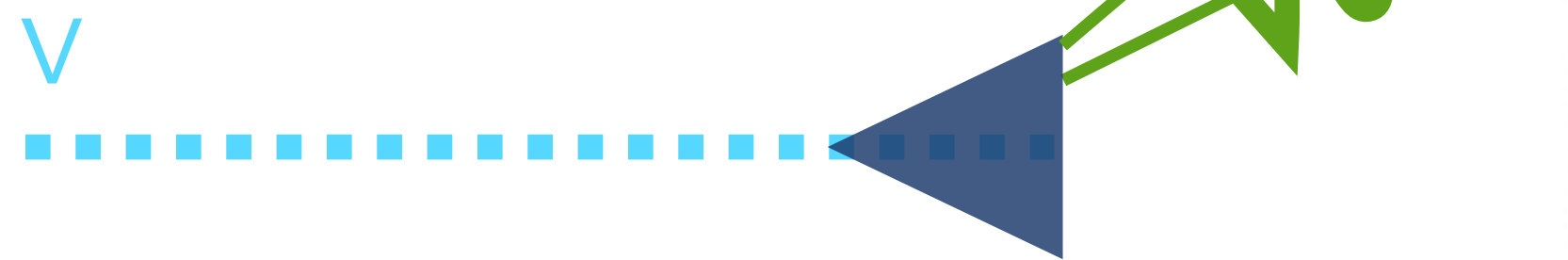
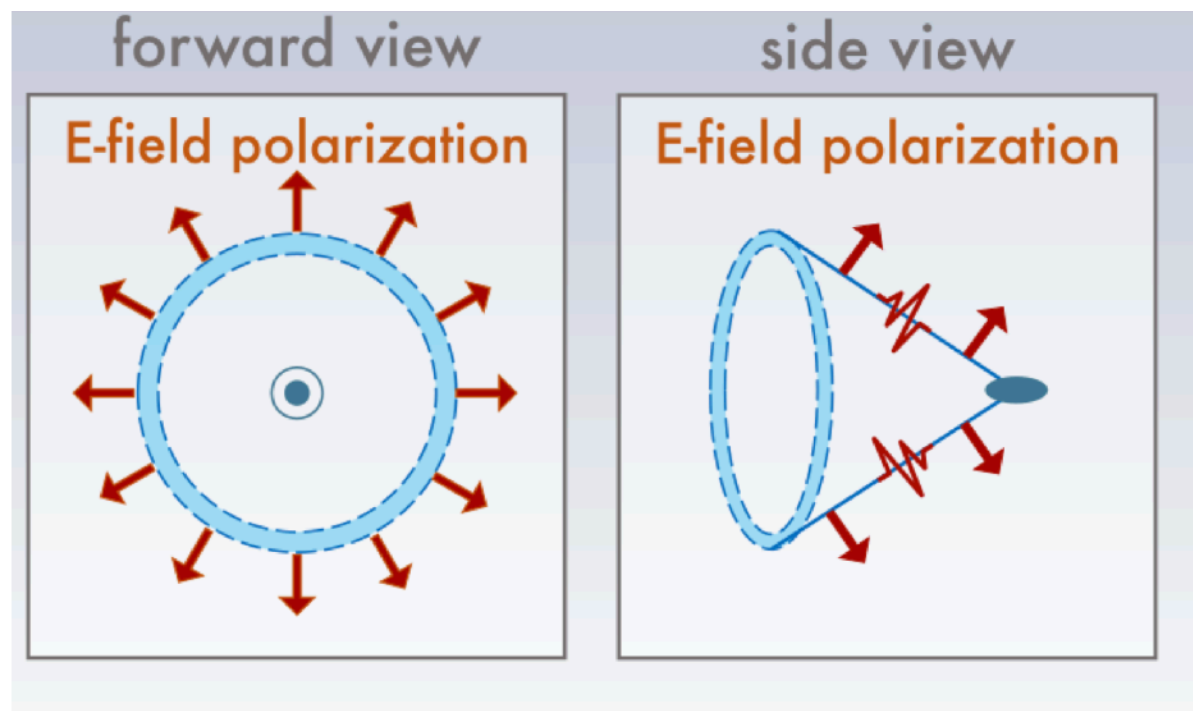
# EXPECTED NEUTRINO SIGNATURES



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Neutrino Event Signatures:

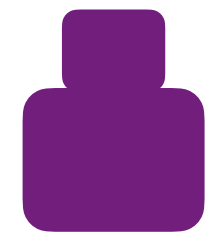
- Impulsive
- MHz-GHz range
- Likely originates from deep ice



# LOTS OF RADIO-BASED EXPERIMENTS



LARGE VOLUME,  
SHORT TIME



ANITA\*,  
PUEO\*

SMALL VOLUME,  
LONG TIME



ARA\*,  
RNO-G\*

BEACON\*,  
TAROGÉ

GRAND

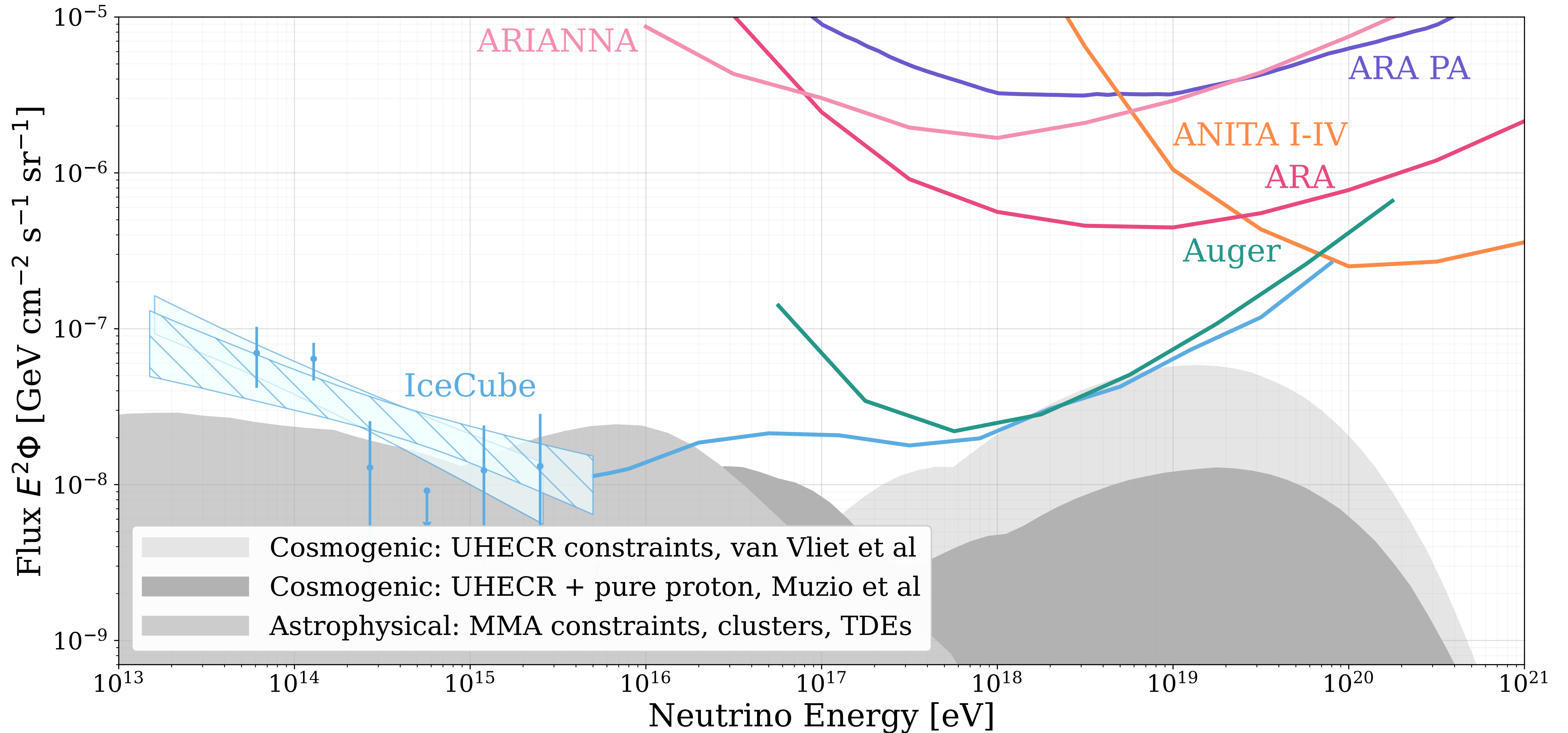
RET

ARIANNA

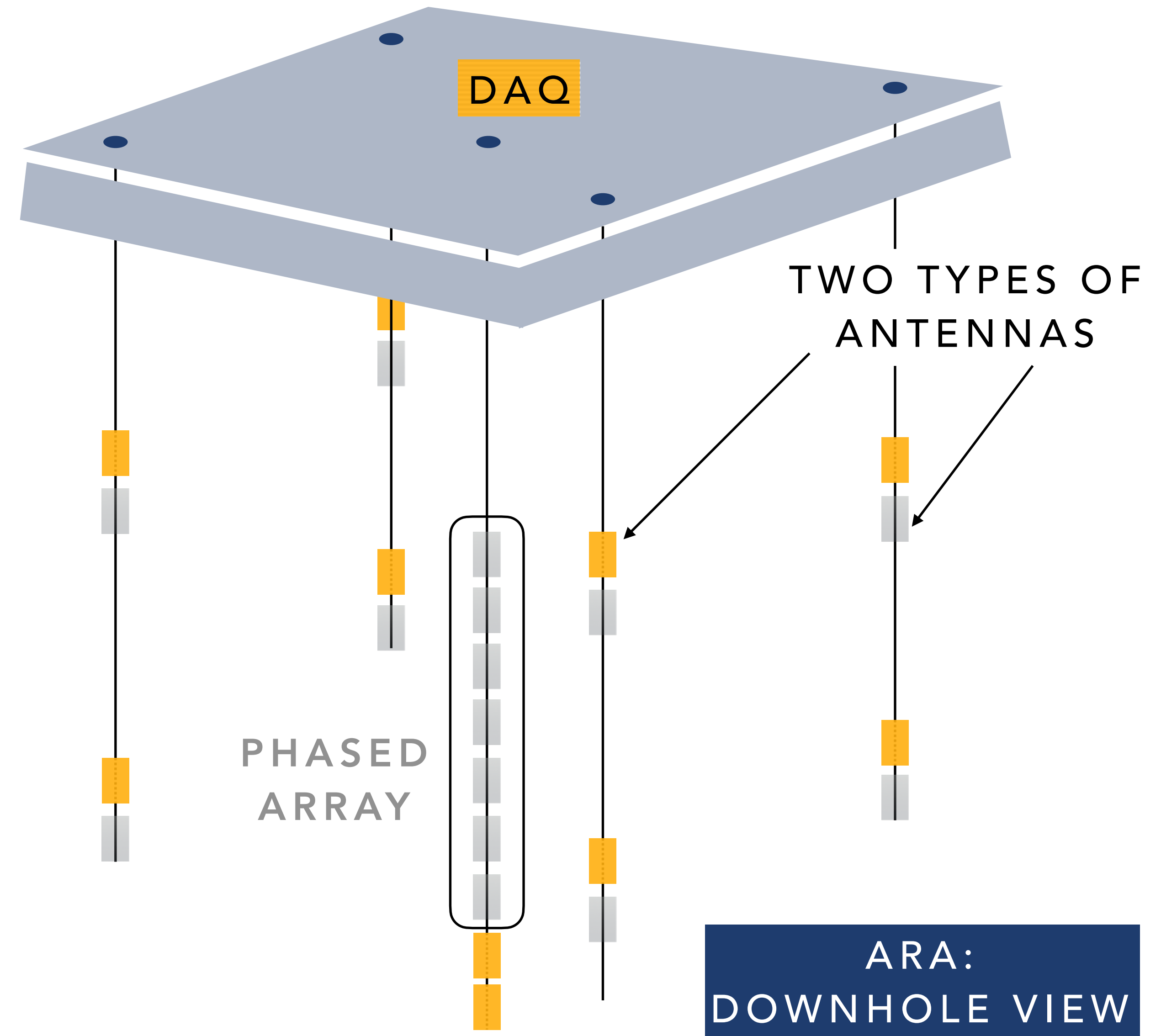
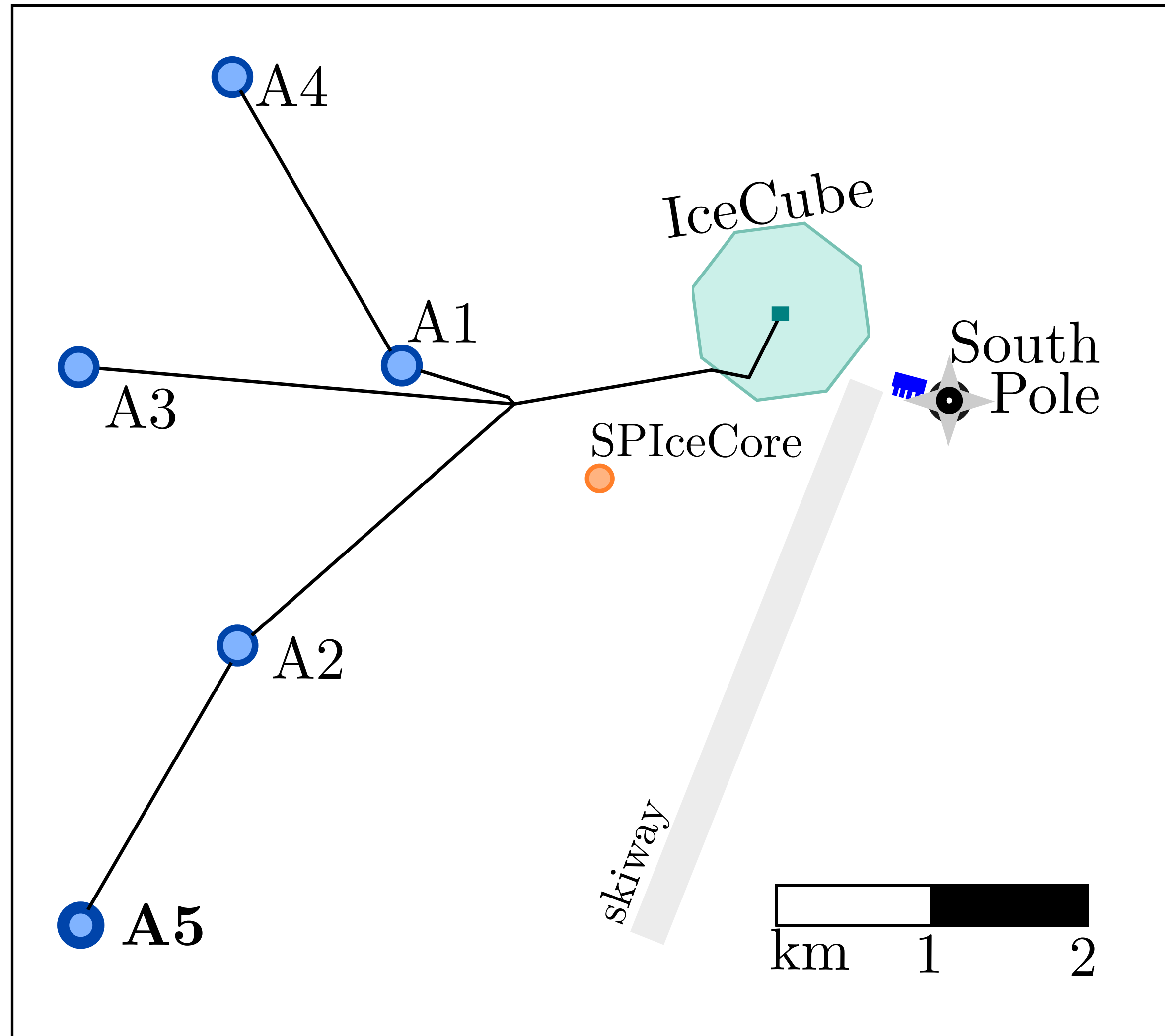
ICE-BASED RADIO EXPERIMENTS  
REQUIRE LESS INSTRUMENTED VOLUME  
THAN OPTICAL EXPERIMENTS

\* I COLLABORATE ON THESE

# THE CURRENT STATE OF THE FIELD

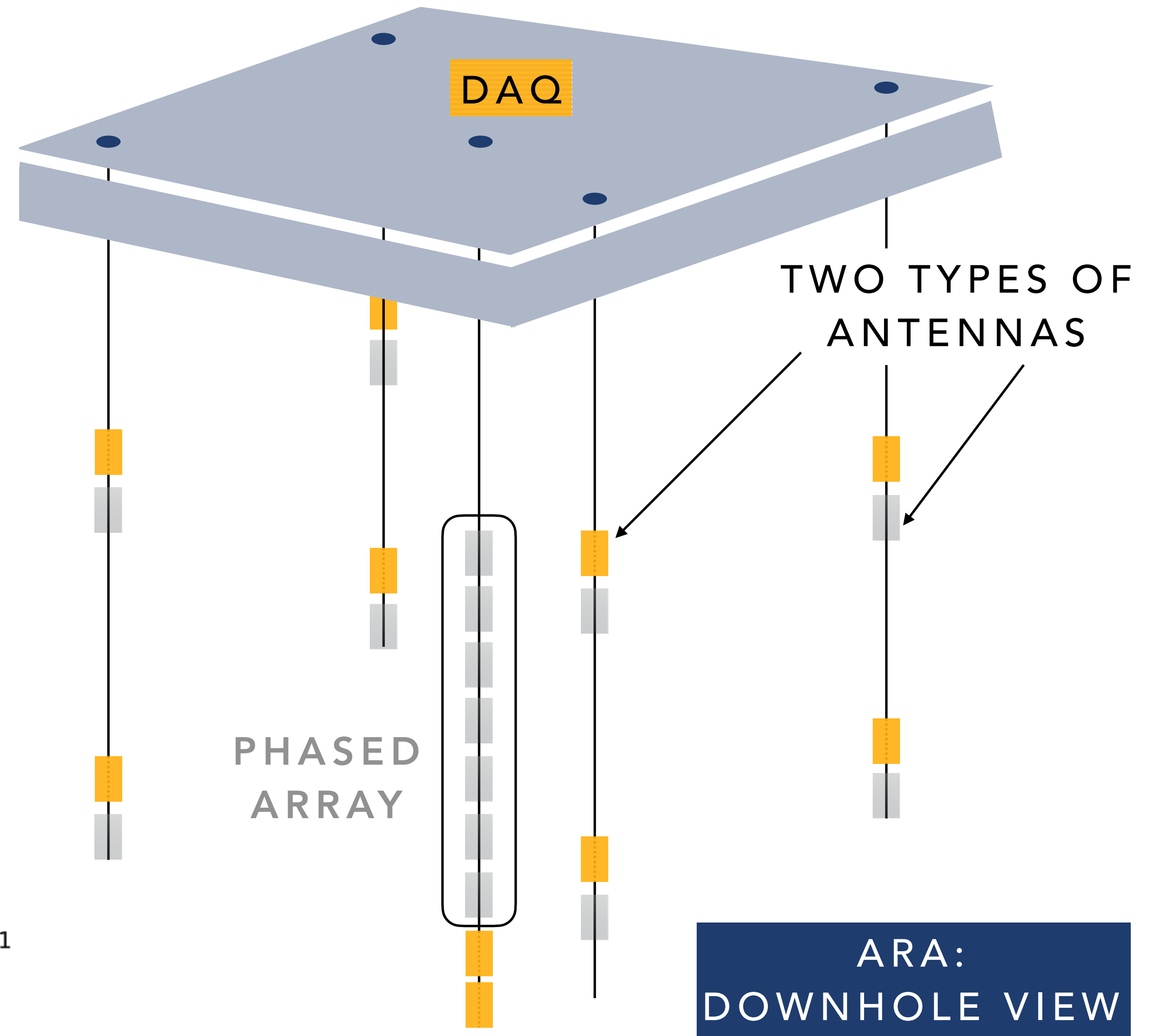
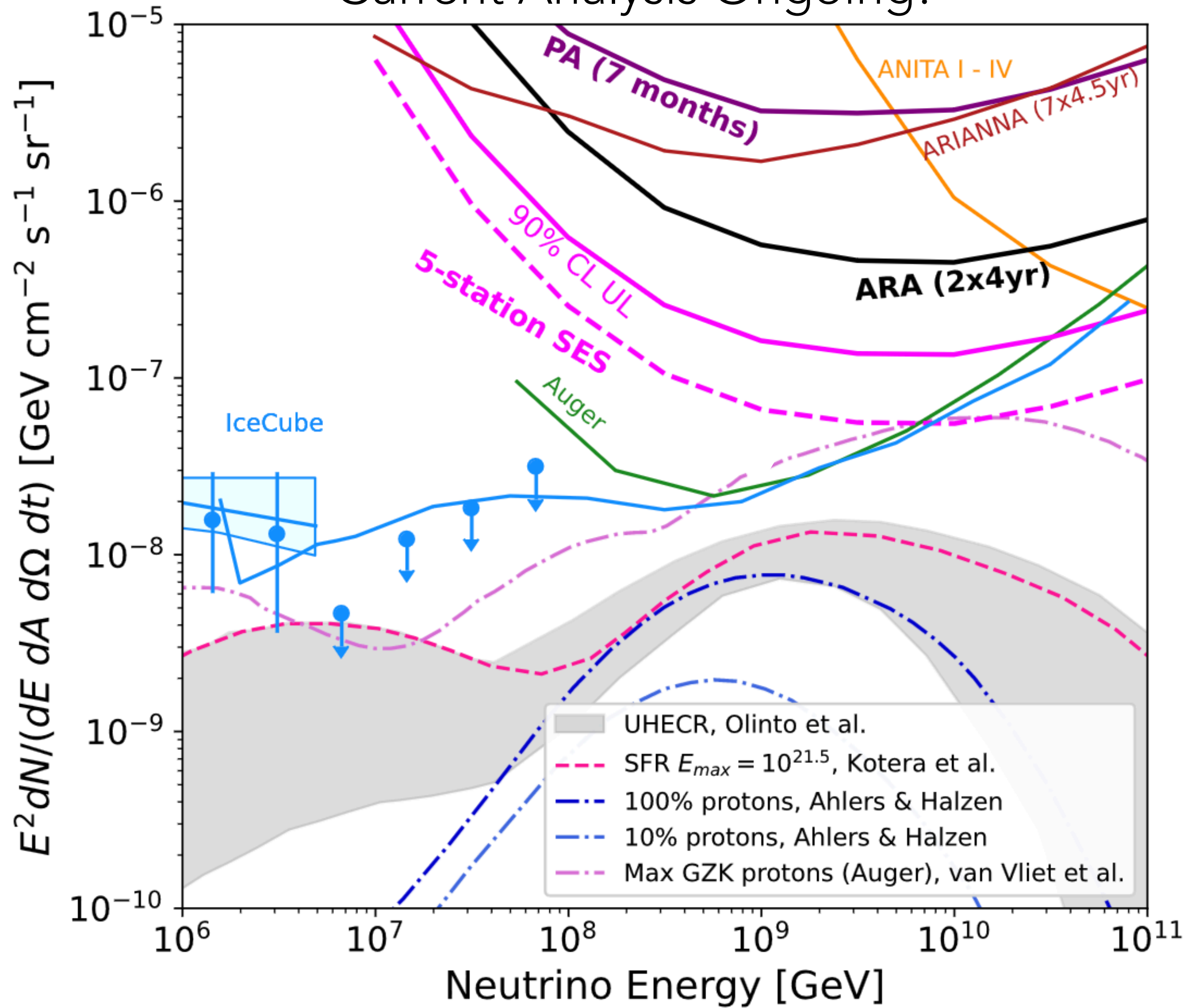


# IN-ICE EXPERIMENTS: ARA



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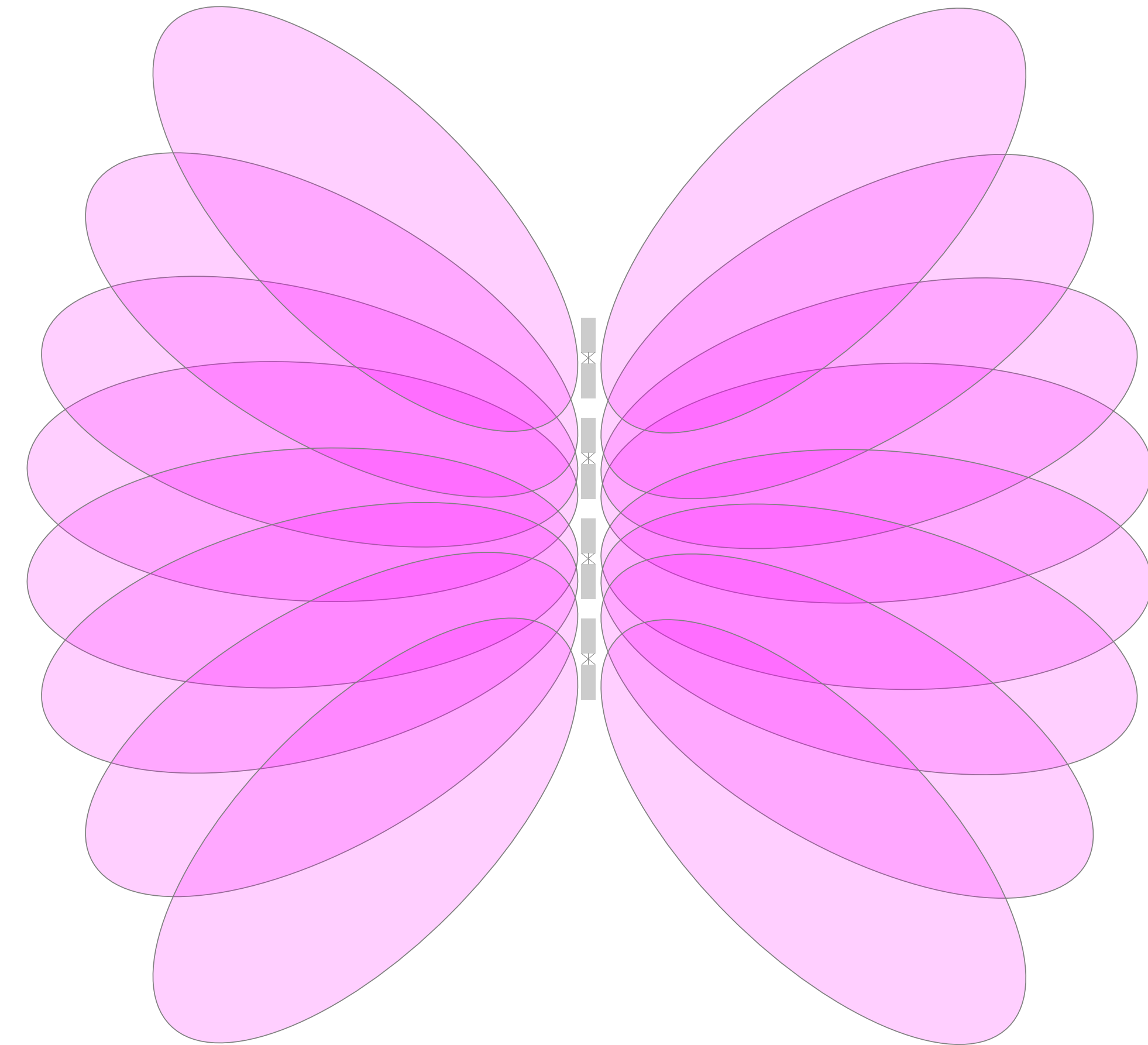
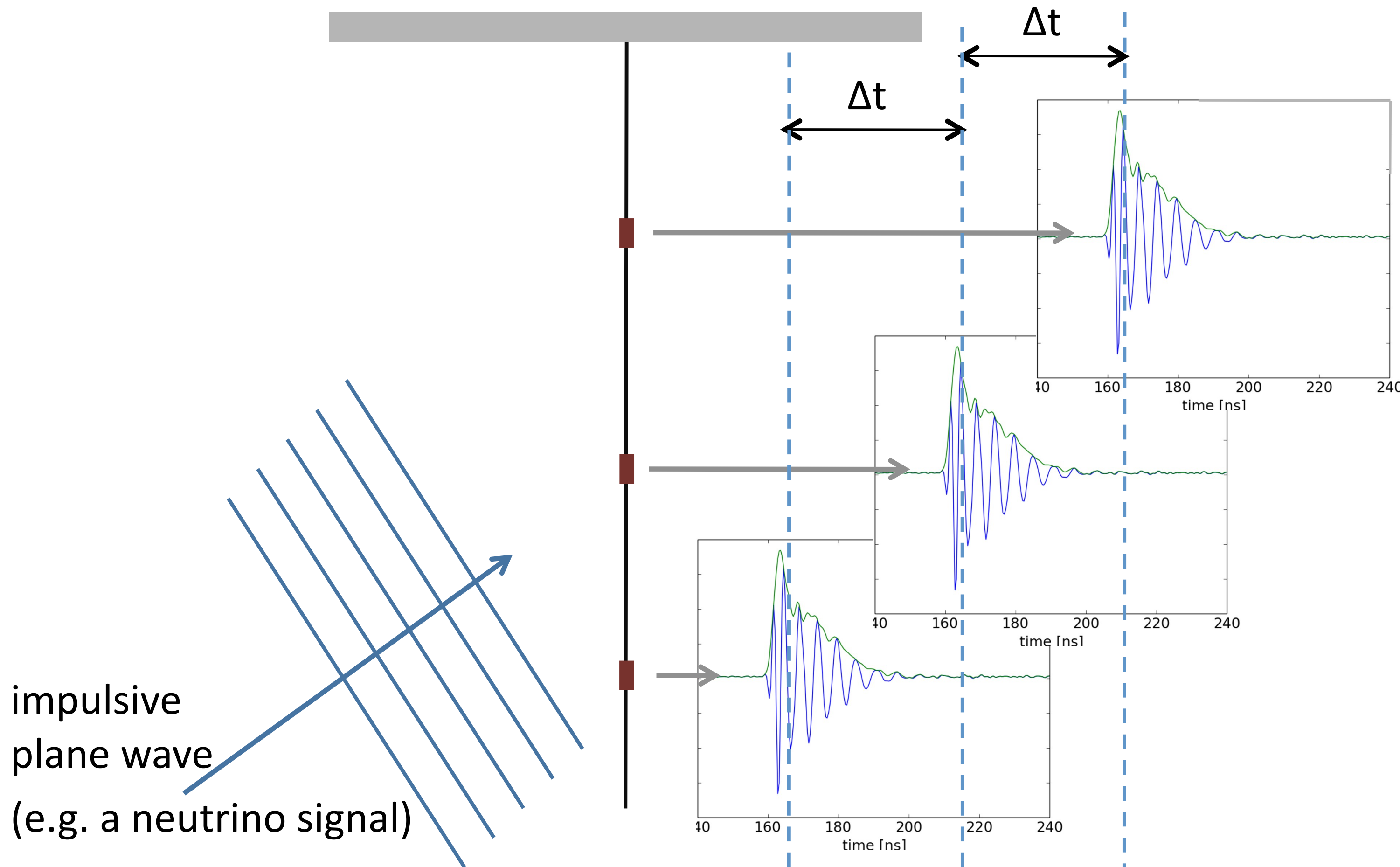
Current Analysis Ongoing!



# A NEW TRIGGER DESIGN MAKES RADIO BETTER

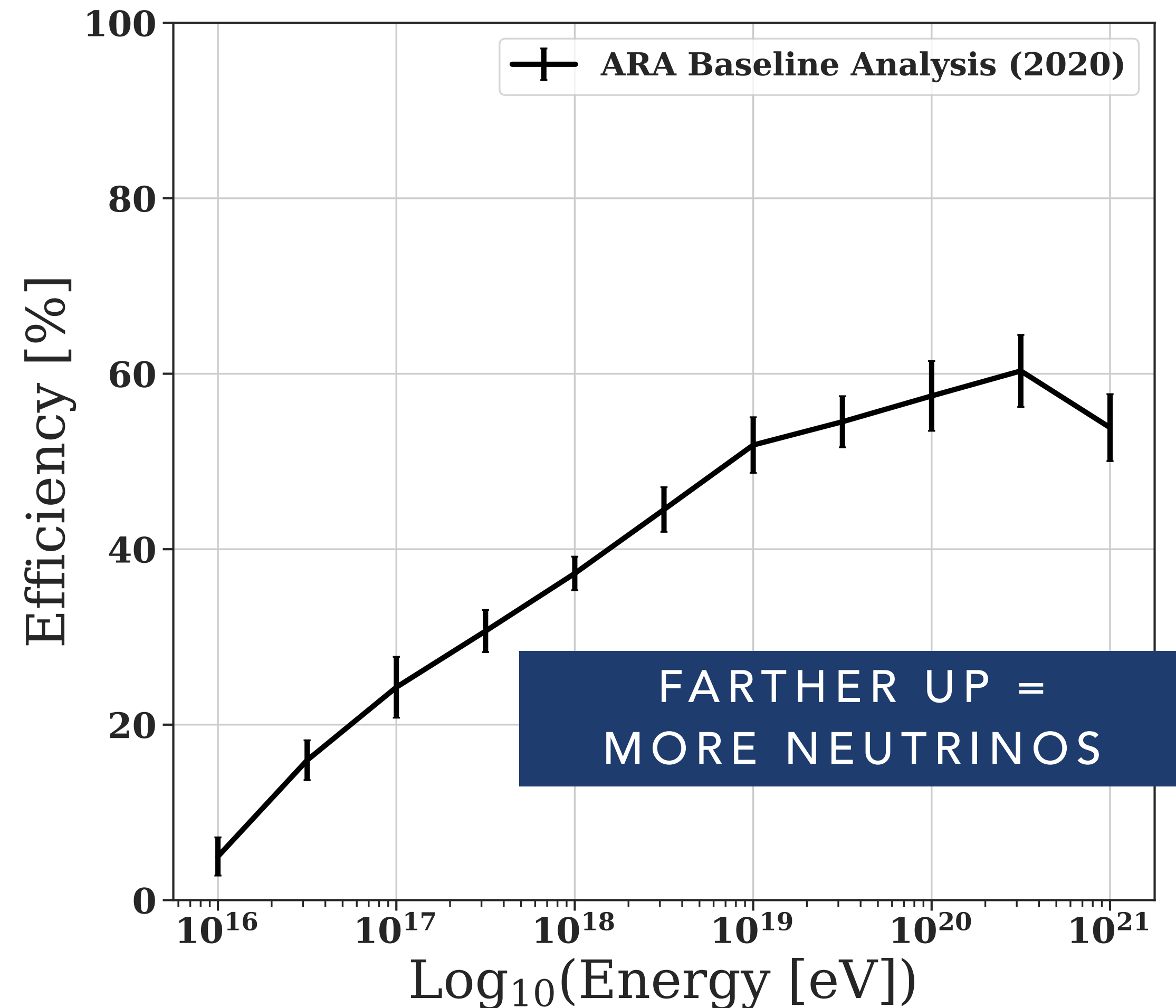
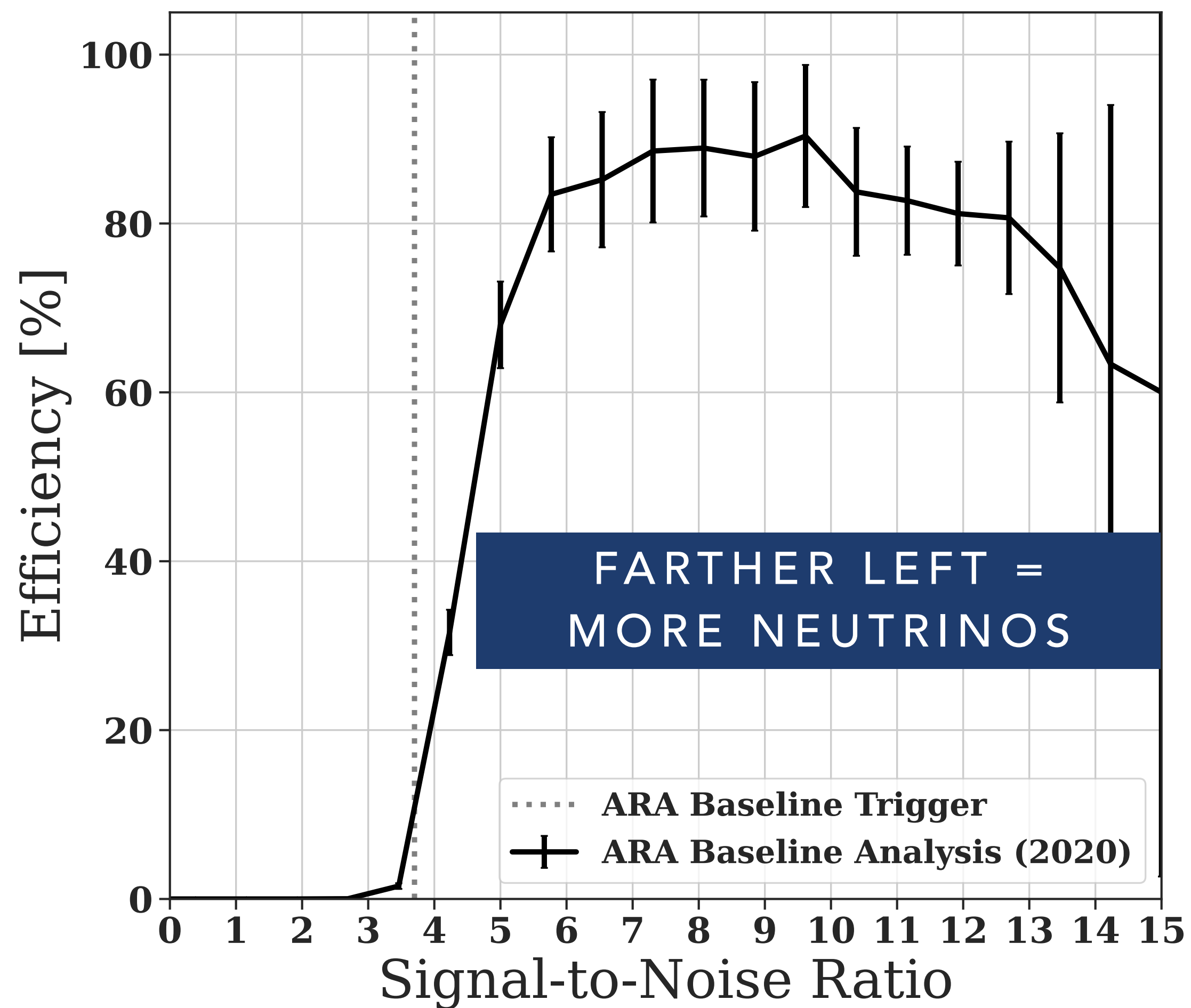
A trigger based on beams:  
a Phased Array Trigger

Side View of a 3 of Antennas in a Hole

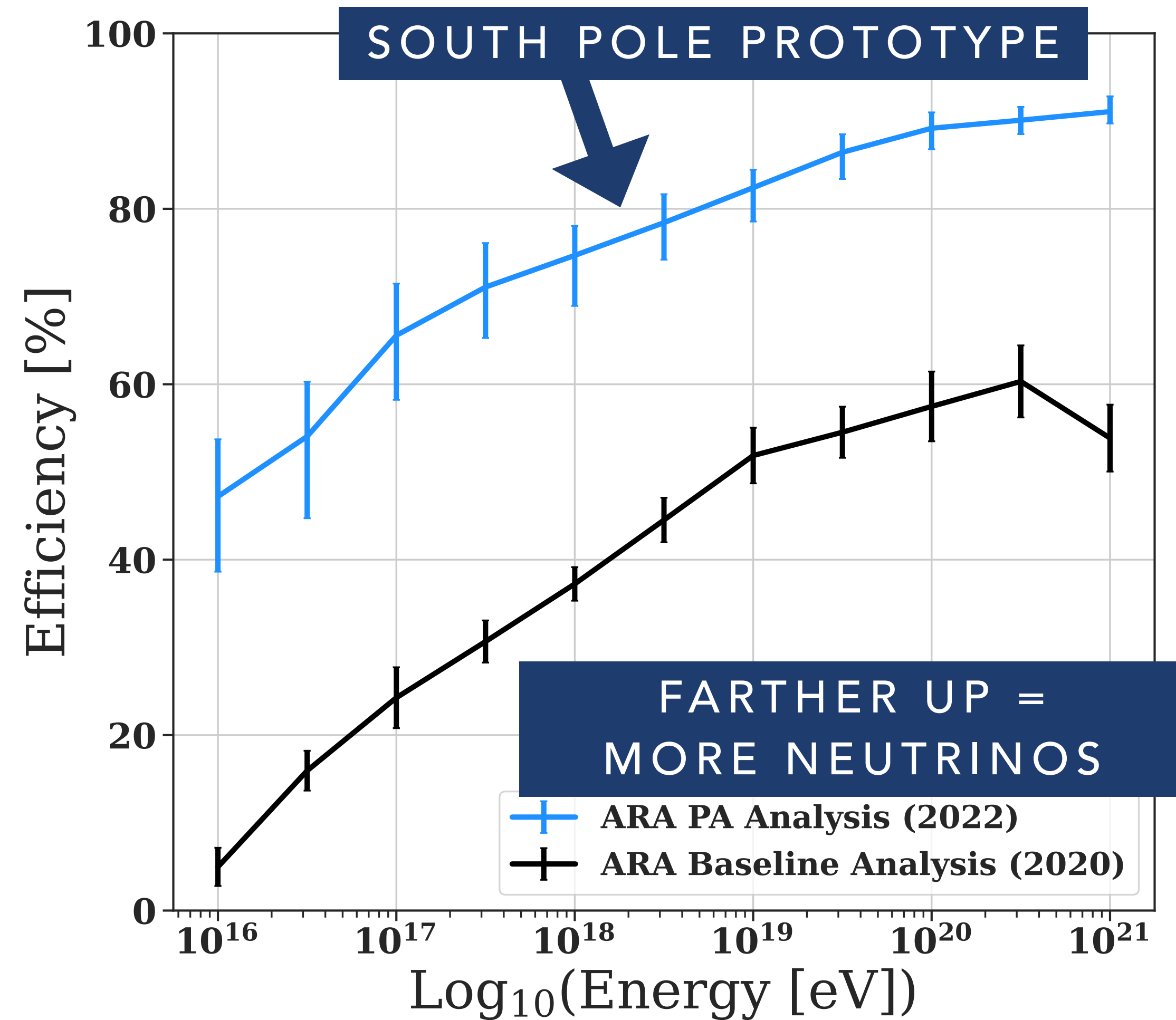
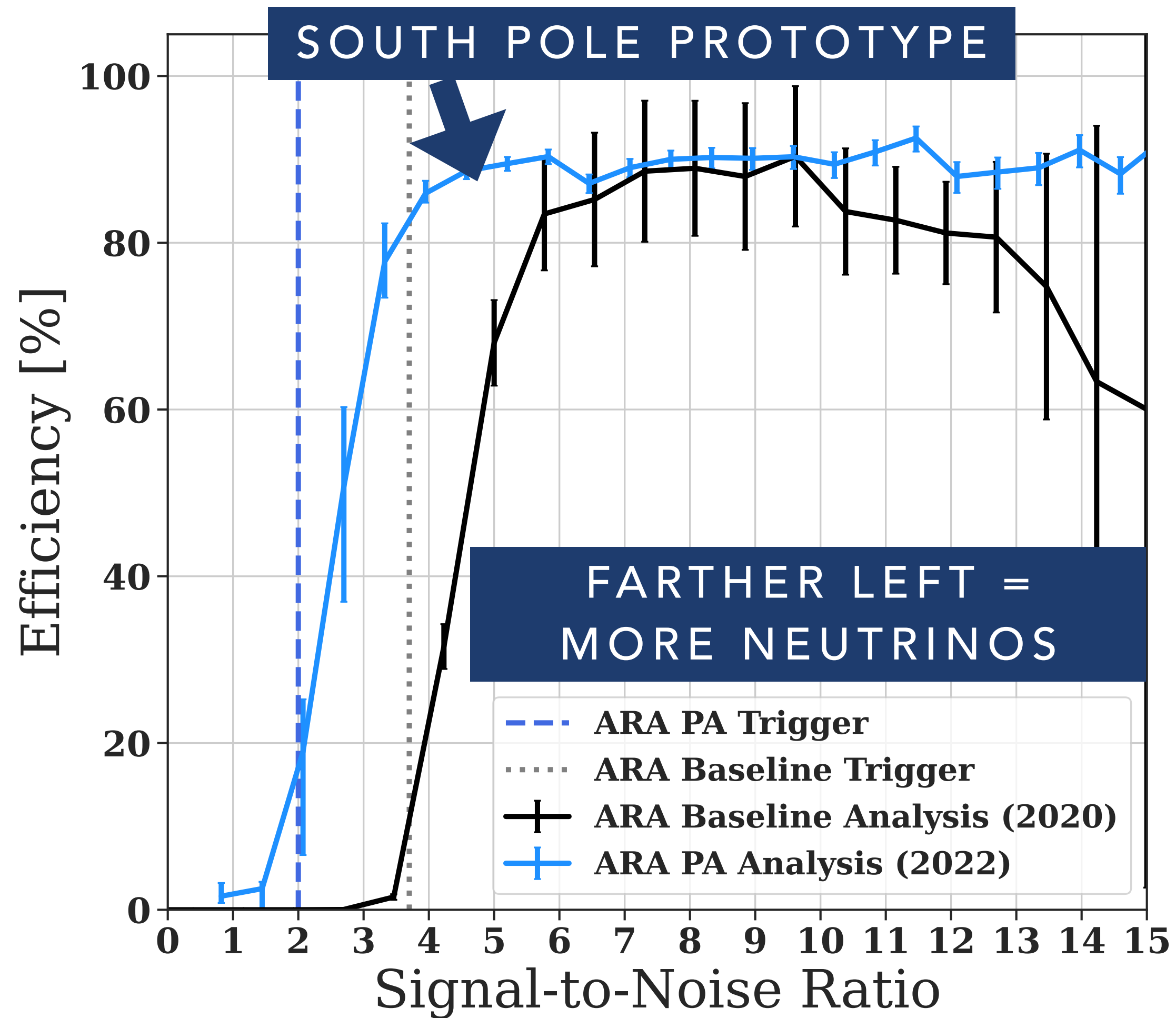




# NEW IN-ICE TRIGGER RESULTS

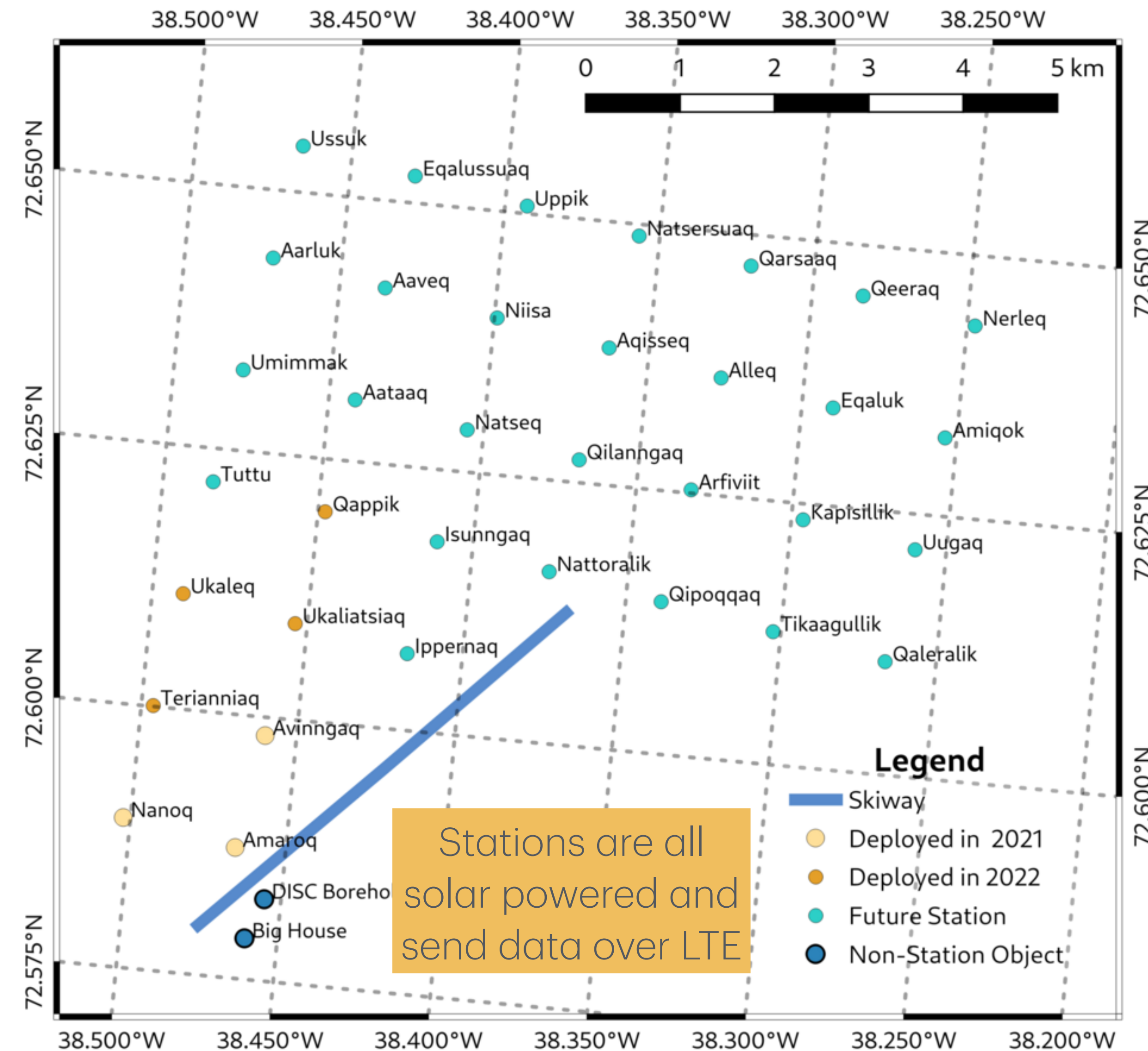


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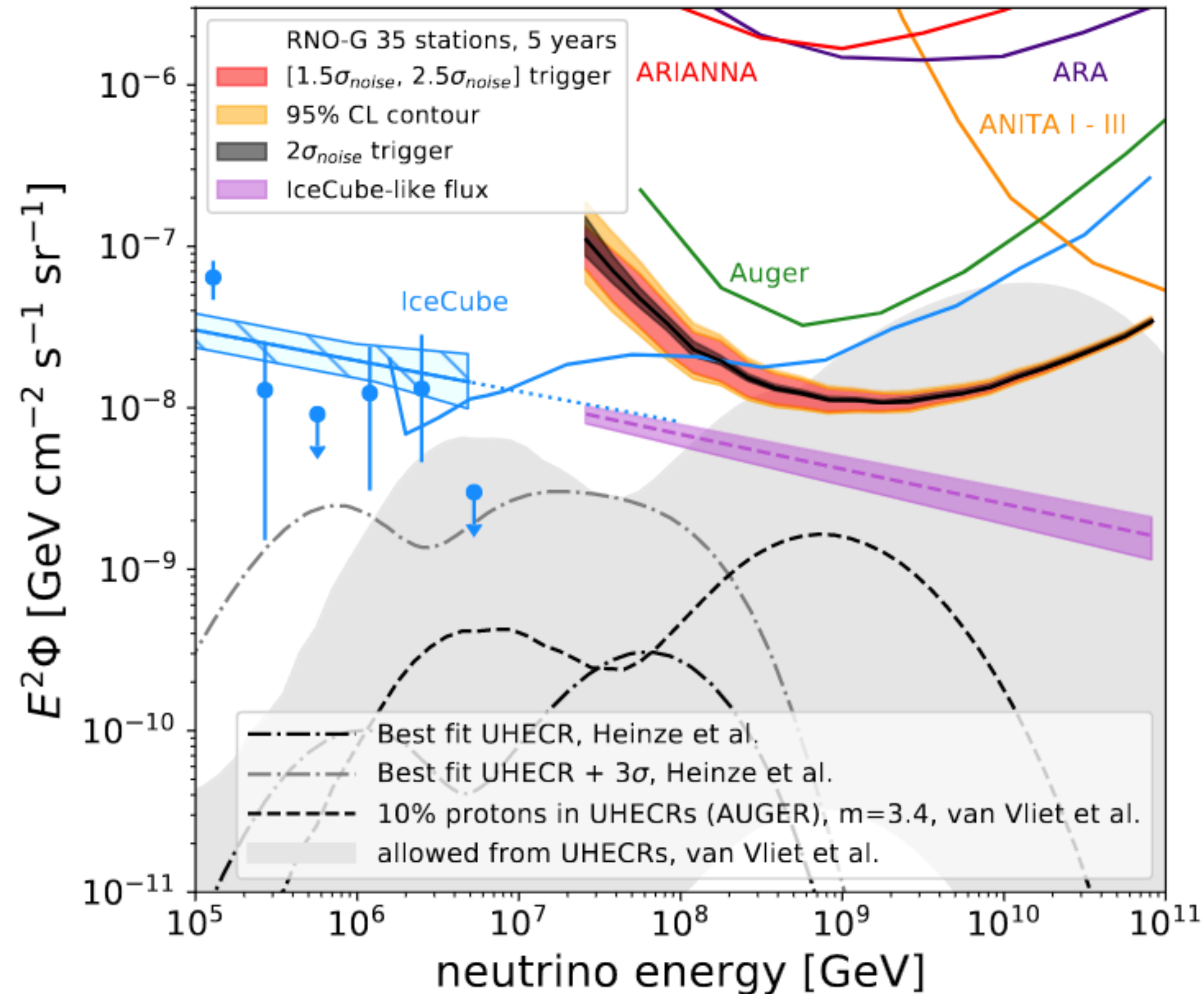
# IN-ICE EXPERIMENTS: RNO-G

- Deployed near Summit Station, Greenland
- Hardware is fully funded to reach 35(+) stations: already the largest in-ice radio neutrino detector by area!
- Currently in building phase: holes for 7 more stations are being drilled this year, with DAQs installed next year
- Science team is also working on calibration, simulation, instrument performance

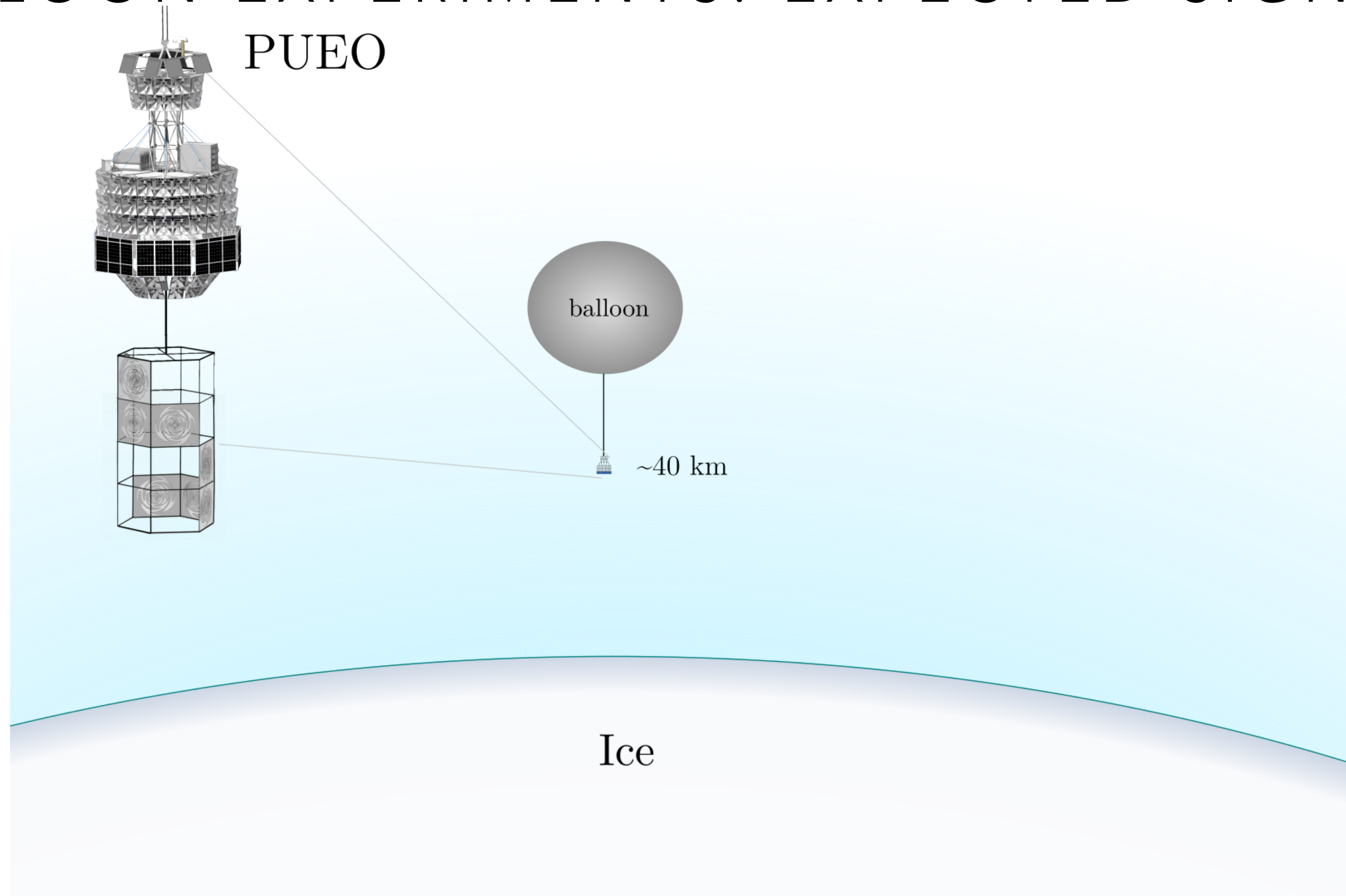


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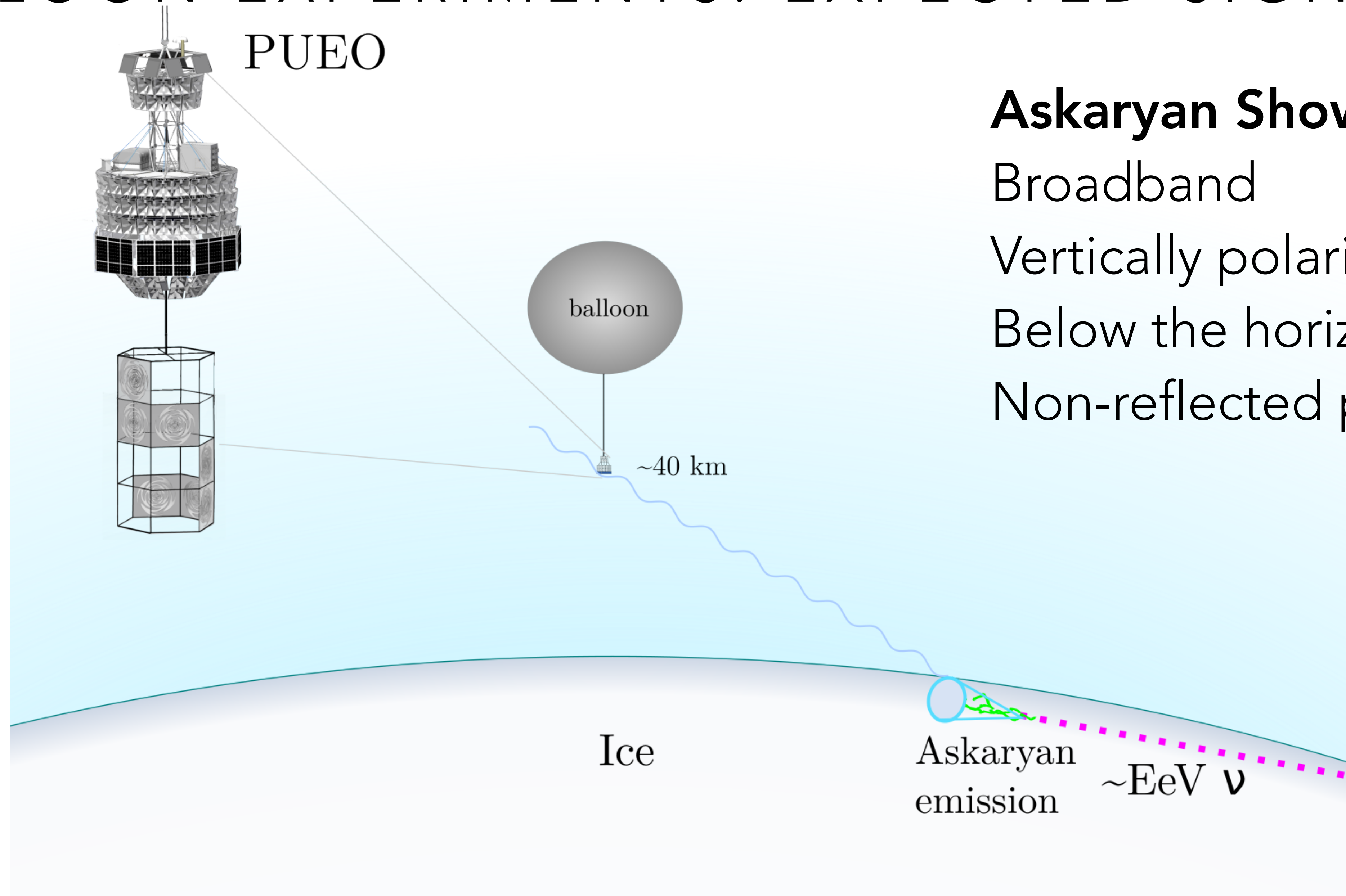
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# BALLOON EXPERIMENTS: EXPECTED SIGNALS

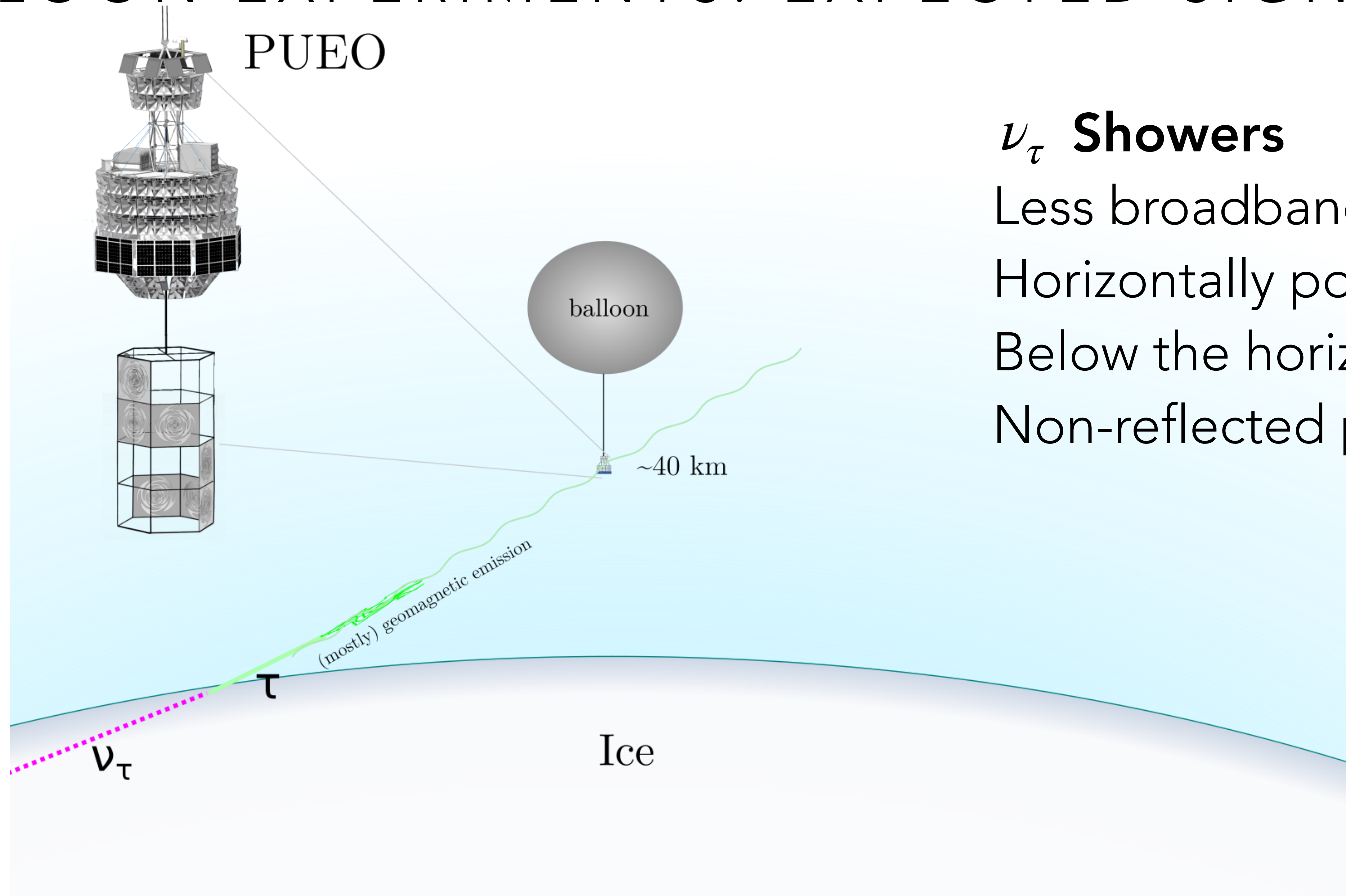


# BALLOON EXPERIMENTS: EXPECTED SIGNALS



**Askaryan Showers**  
Broadband  
Vertically polarized  
Below the horizon  
Non-reflected polarity

# BALLOON EXPERIMENTS: EXPECTED SIGNALS



## $\nu_\tau$ Showers

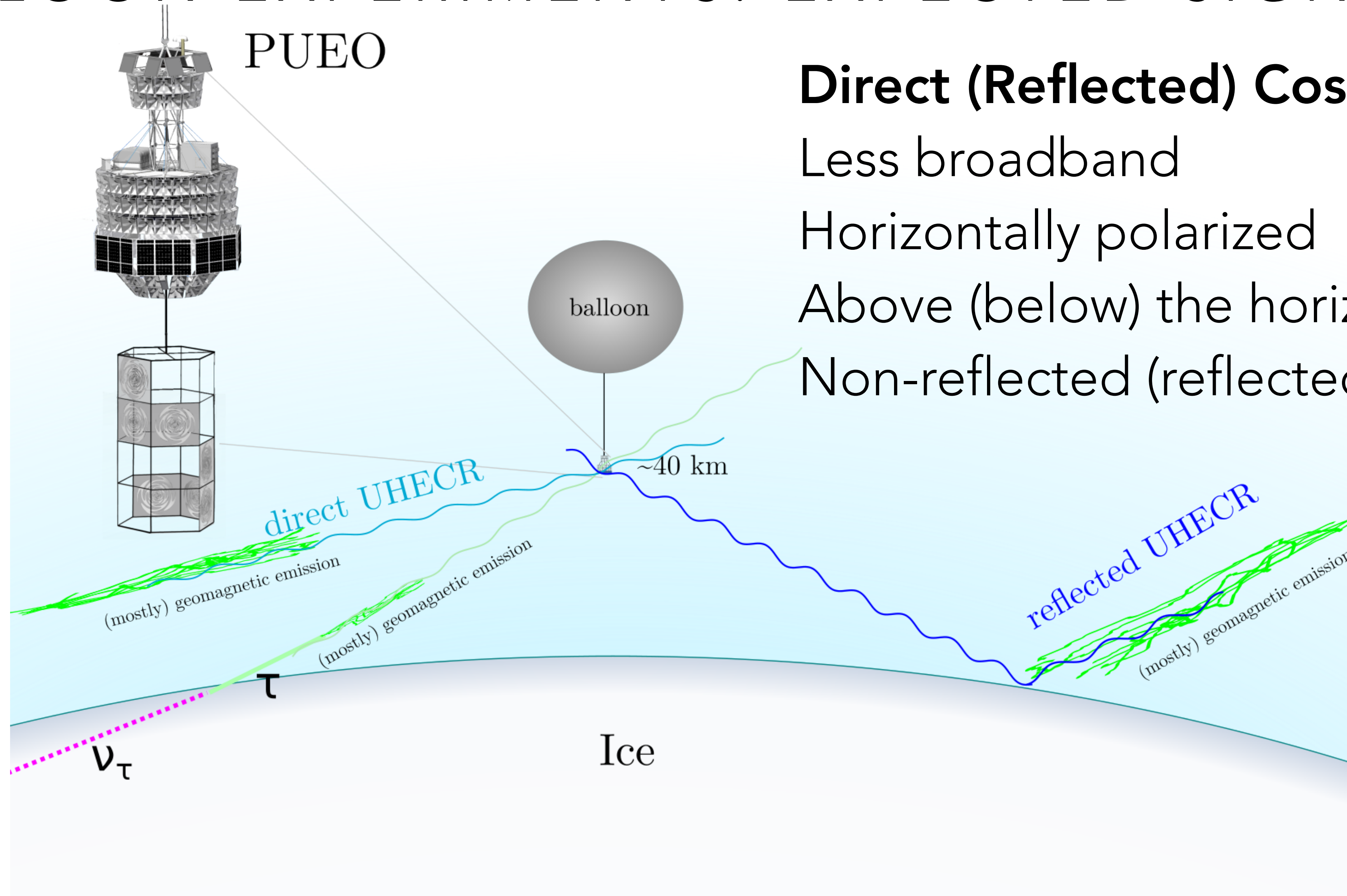
Less broadband

Horizontally polarized

Below the horizon

Non-reflected polarity

# BALLOON EXPERIMENTS: EXPECTED SIGNALS



## Direct (Reflected) Cosmic Rays:

Less broadband

Horizontally polarized

Above (below) the horizon

Non-reflected (reflected) polarity



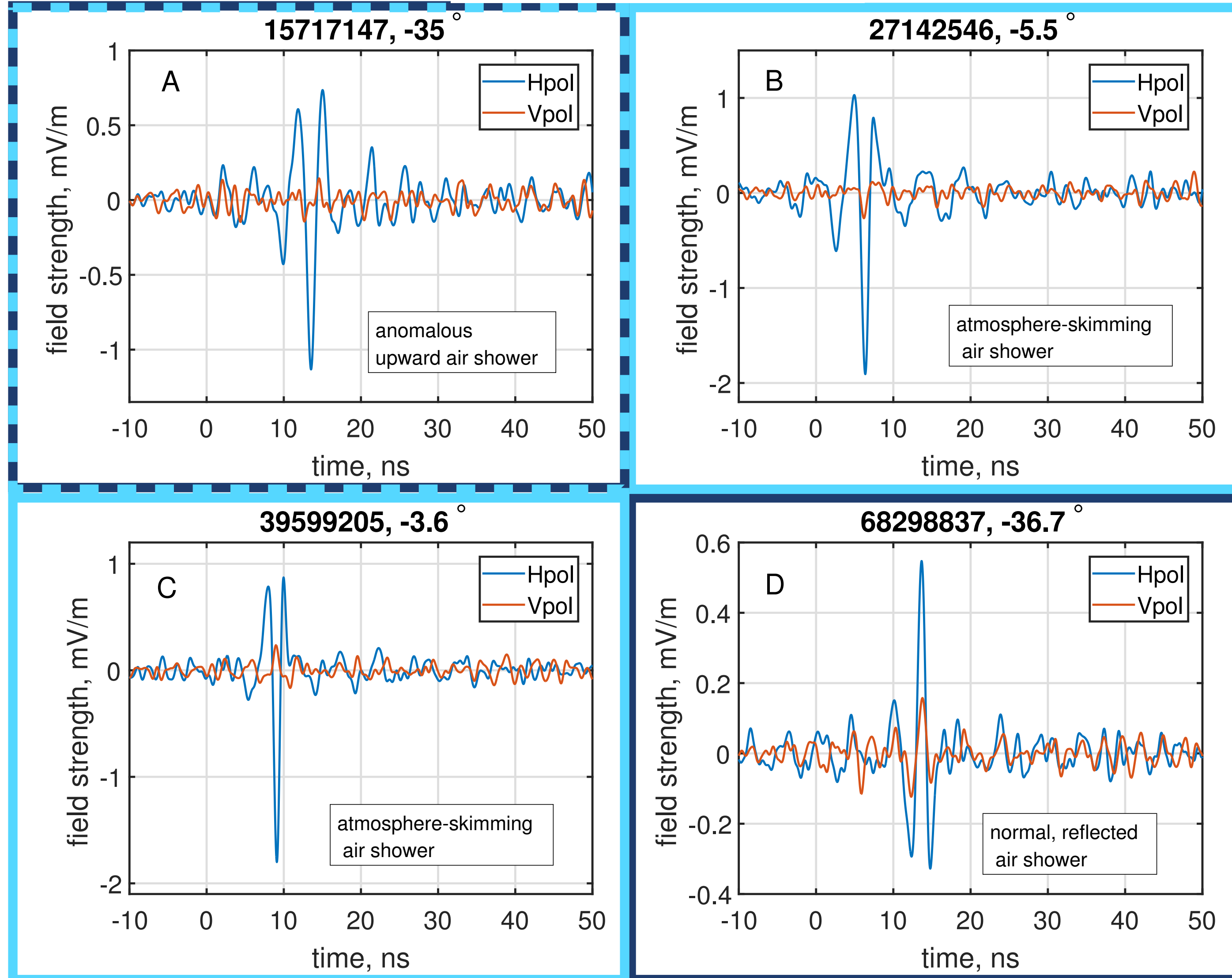
# BALLOON EXPERIMENTS: ANITA VS. PUEO



Coincidence Trigger → Phased Array trigger → higher trigger efficiency  
200 MHz cutoff → 300 MHz cutoff and more antennas → better reconstruction  
Low frequency instrument → improved air shower channel

# THE ANITA ANOMALOUS EVENTS

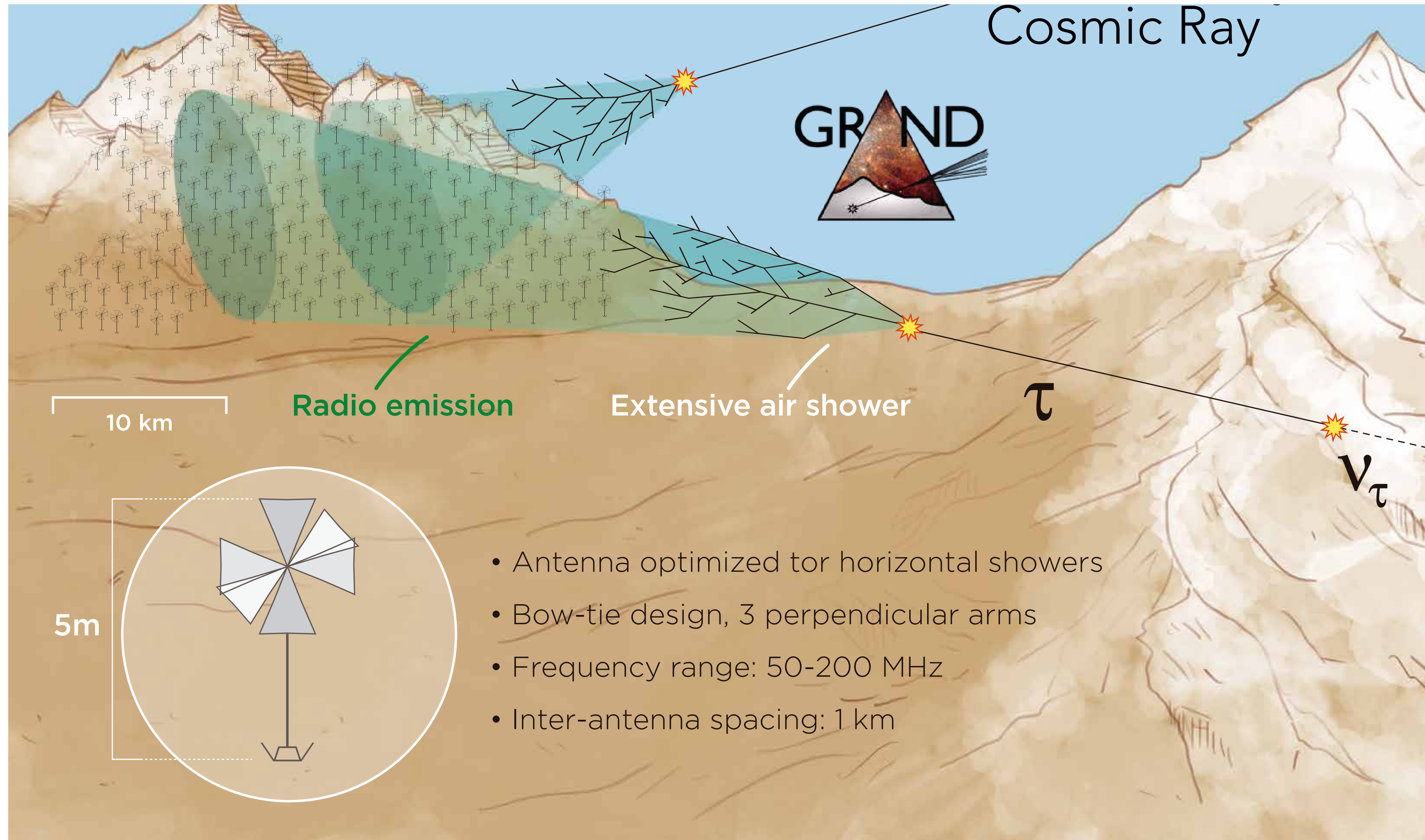
ANITA III Air Showers



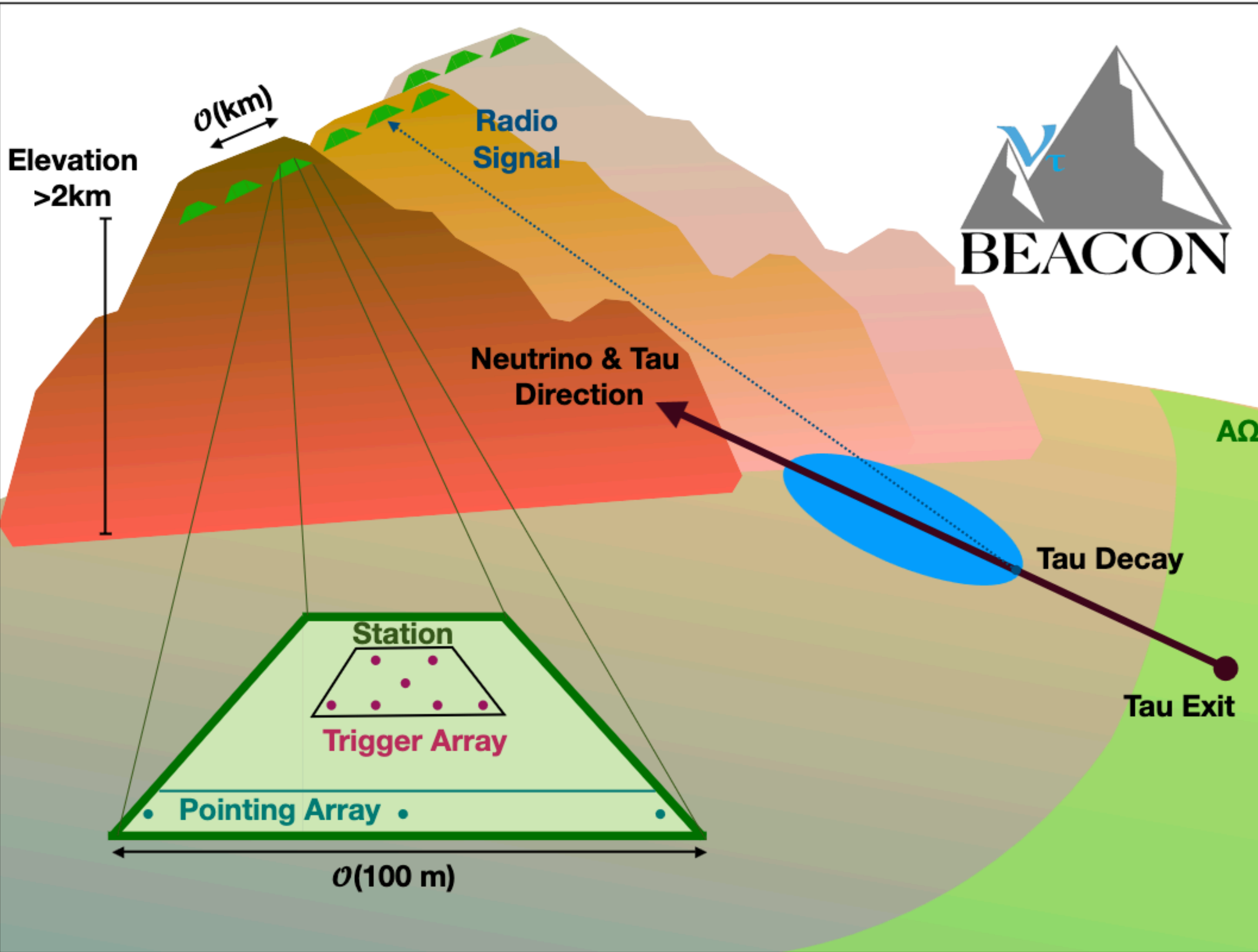
■ Reflected air shower  
■ Direct air shower

- 3/4 ANITA flights saw "anomalous events": inconsistent directions and polarities
- Will PUEO see more? Stay tuned for flight in 2025!

# $\nu_\tau$ EXPERIMENTS: GRAND AND BEACON (AND OTHERS!)



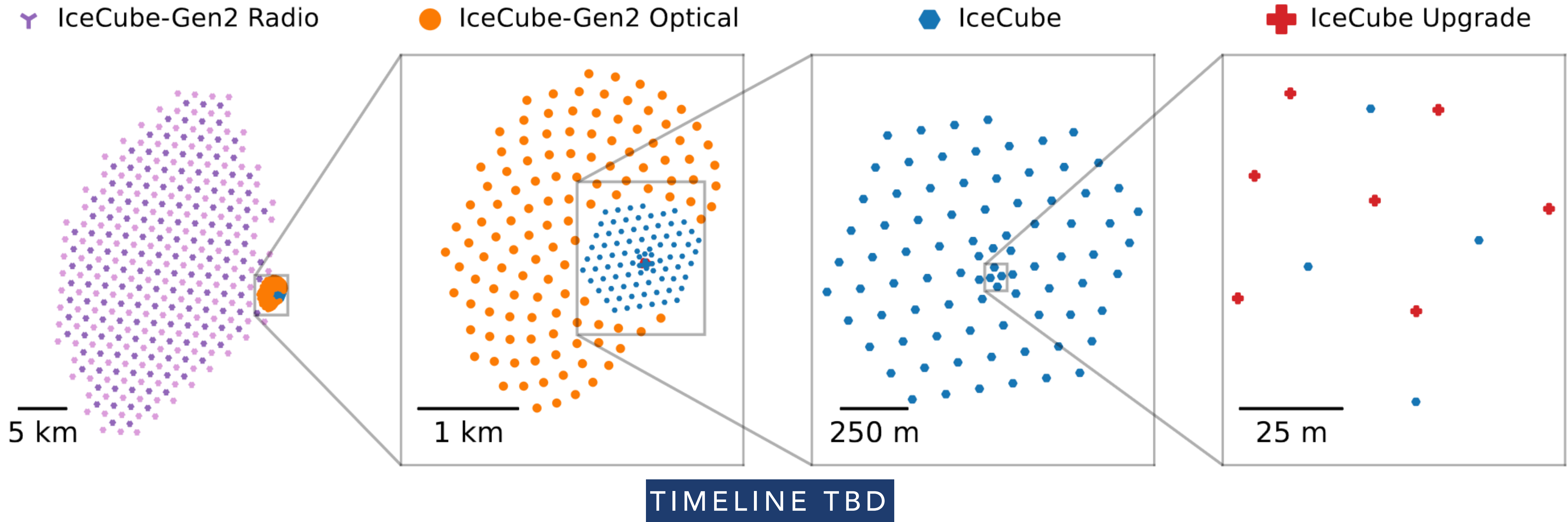
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*Prospects for High-Elevation Radio Detection of  $>100$  PeV Tau Neutrinos (2020)*

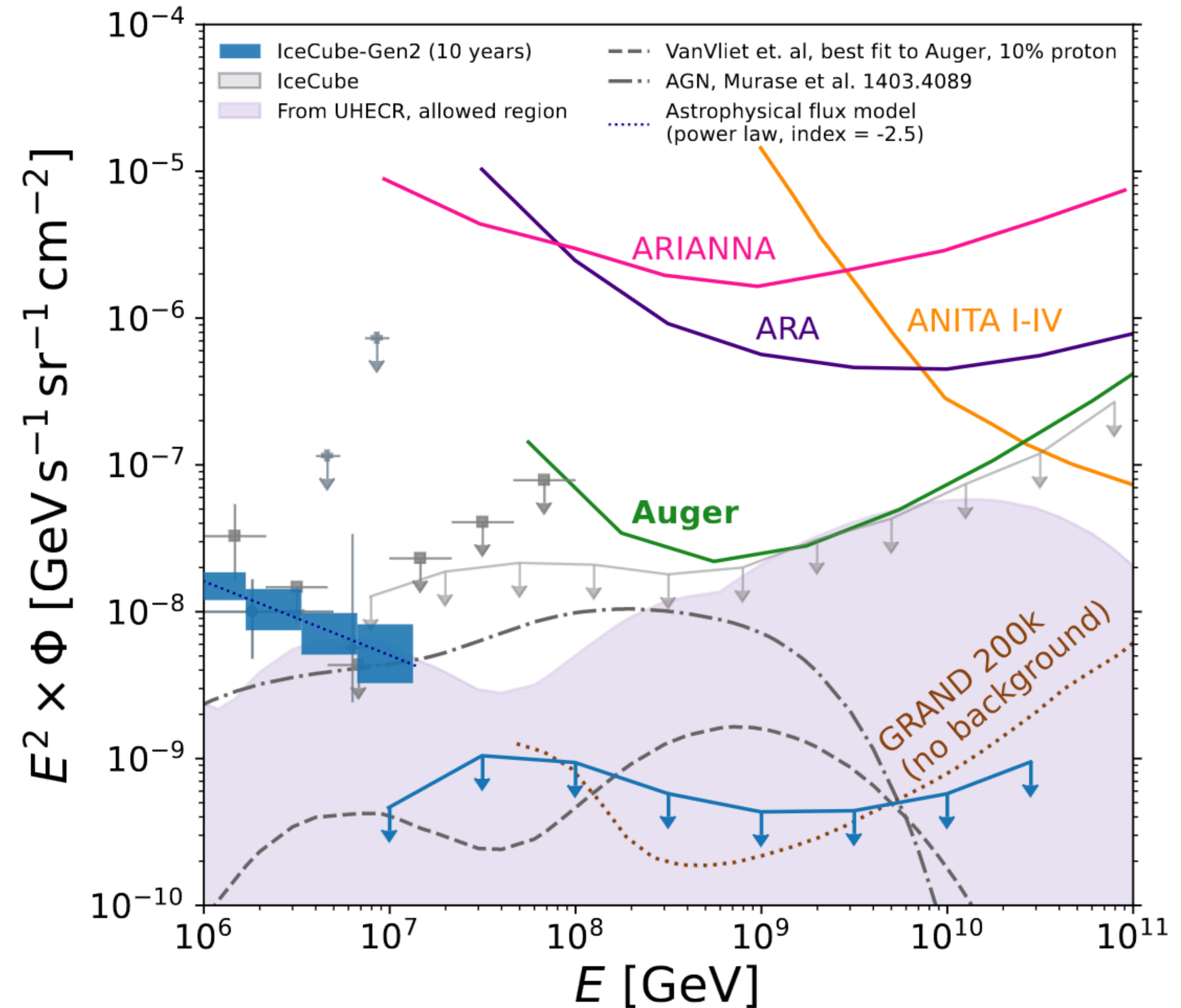


# THE FUTURE: ICECUBE-GEN2 OBSERVATORY



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- IceCube-Gen 2 will capitalize on advancements in both optical and radio detection
- Biggest difficulty is logistics; science case is very strong (recommended by P5 and Astro 2020 Decadal Survey!)



# SUMMARY

- The radio technique is a promising method that can detect neutrinos at the highest known energies
- Two+ decades of prototyping and instrument design have brought us nearly into discovery territory
- Stay tuned for more results coming in the next five years!

