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UHE Neutrino Search with the Askaryan Radio Array at the South Pole

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UHE Neutrino Search with the **Askaryan Radio Array** at the **South Pole**

The Big Questions



Who?

ARA

Where?

South Pole

Why ?

How ?

UHE — Ultra High Energy

By “UHE”, I mean “ $E_\nu > 30 \text{ PeV}$ ”

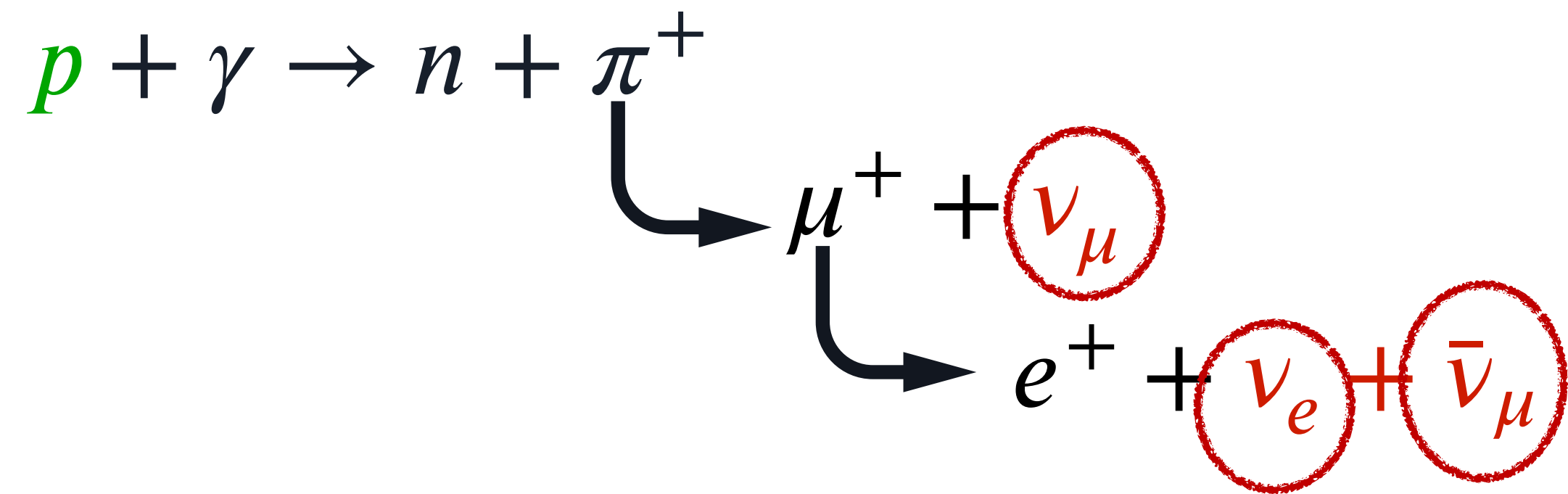
1 PeV = 10^{15} eV

2012 ! IceCube detected a few PeV neutrinos

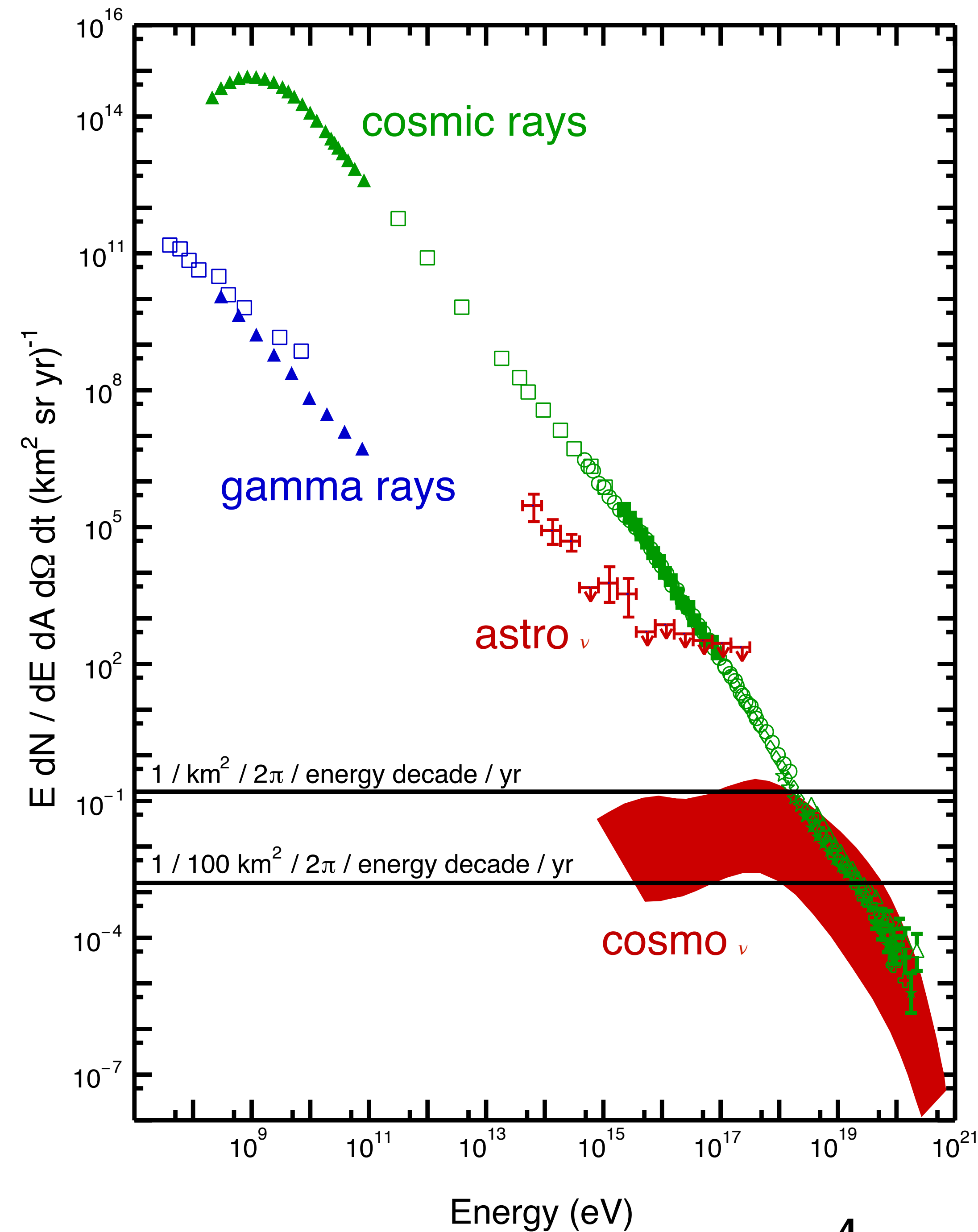
AGN, NGC 1068



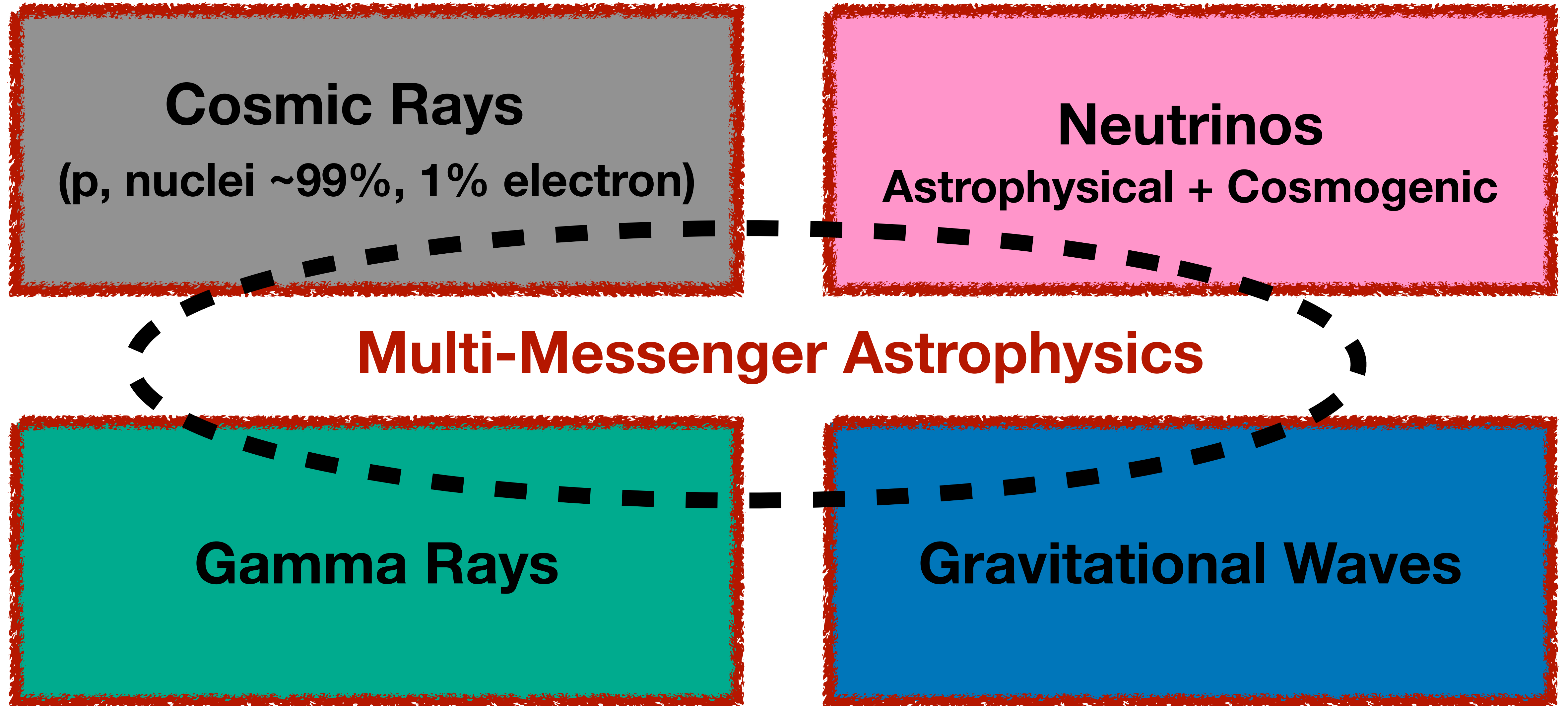
Pions from the GZK interaction further decay



Cosmogenic Neutrinos



Exciting Era of Multi-Messenger Astrophysics



Why Study Neutrinos ?

1. Cosmic rays

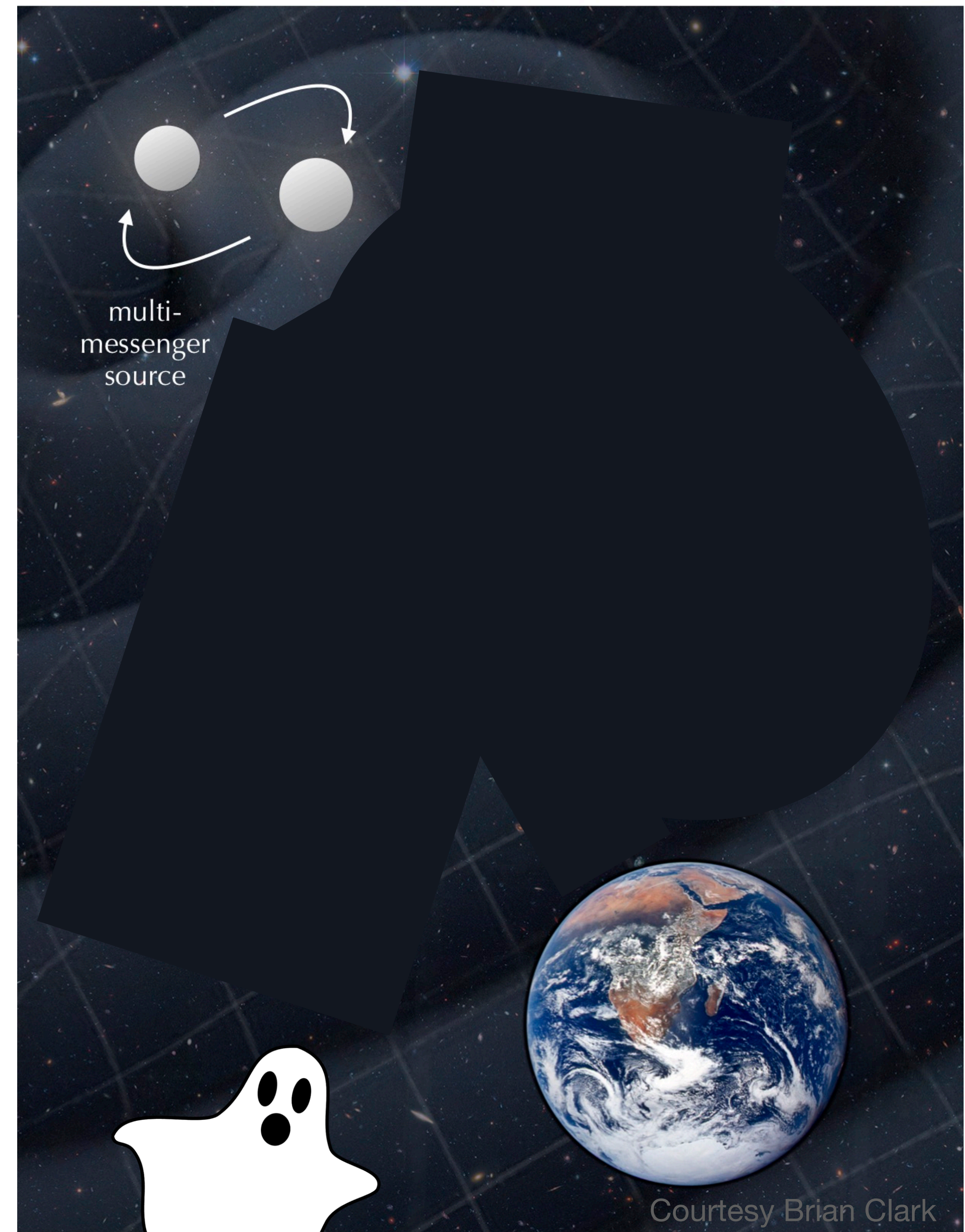
- **Bent by magnetic field**

2. Gamma rays: absorbed by CMB, EBL, dust

3. GW : Hard to point back to the source

4. Neutrinos open unique window to the high energy Universe.

**Challenge : weakly interacting,
We need enormous volume of detector**

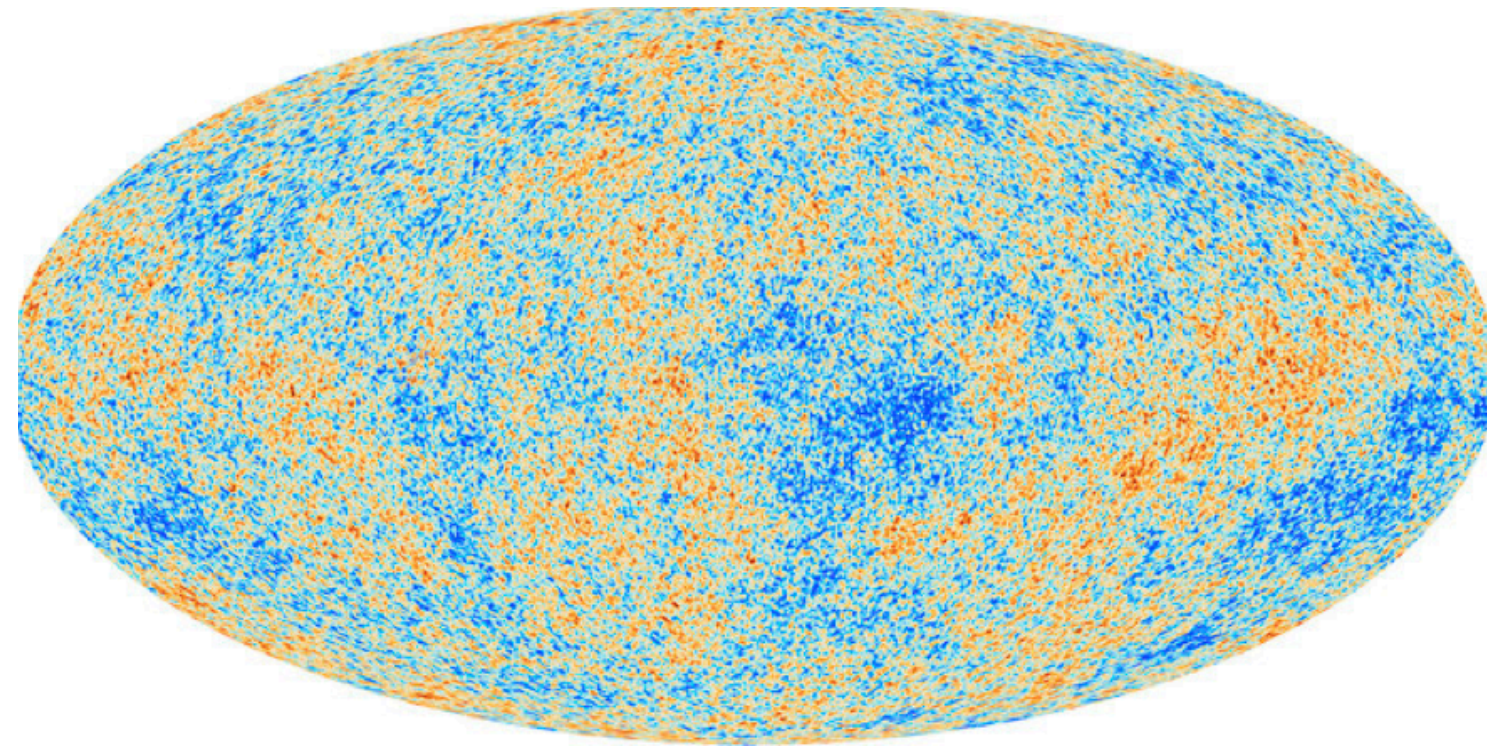


UHE Neutrino production: The GZK process

Cosmic Ray



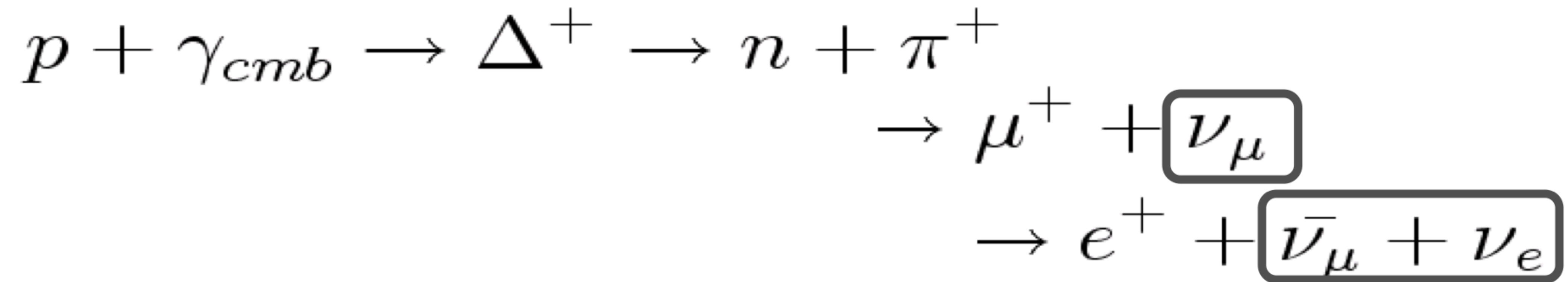
CMB photons



+

=

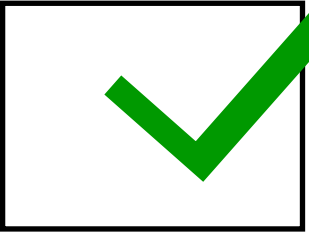
Neutrino beam !



The Big Questions

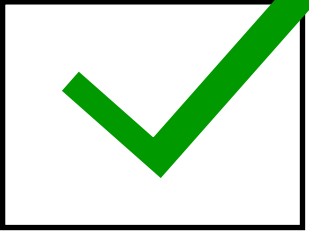


Who?



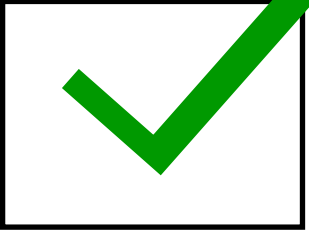
ARA

Where?



South Pole

Why ?



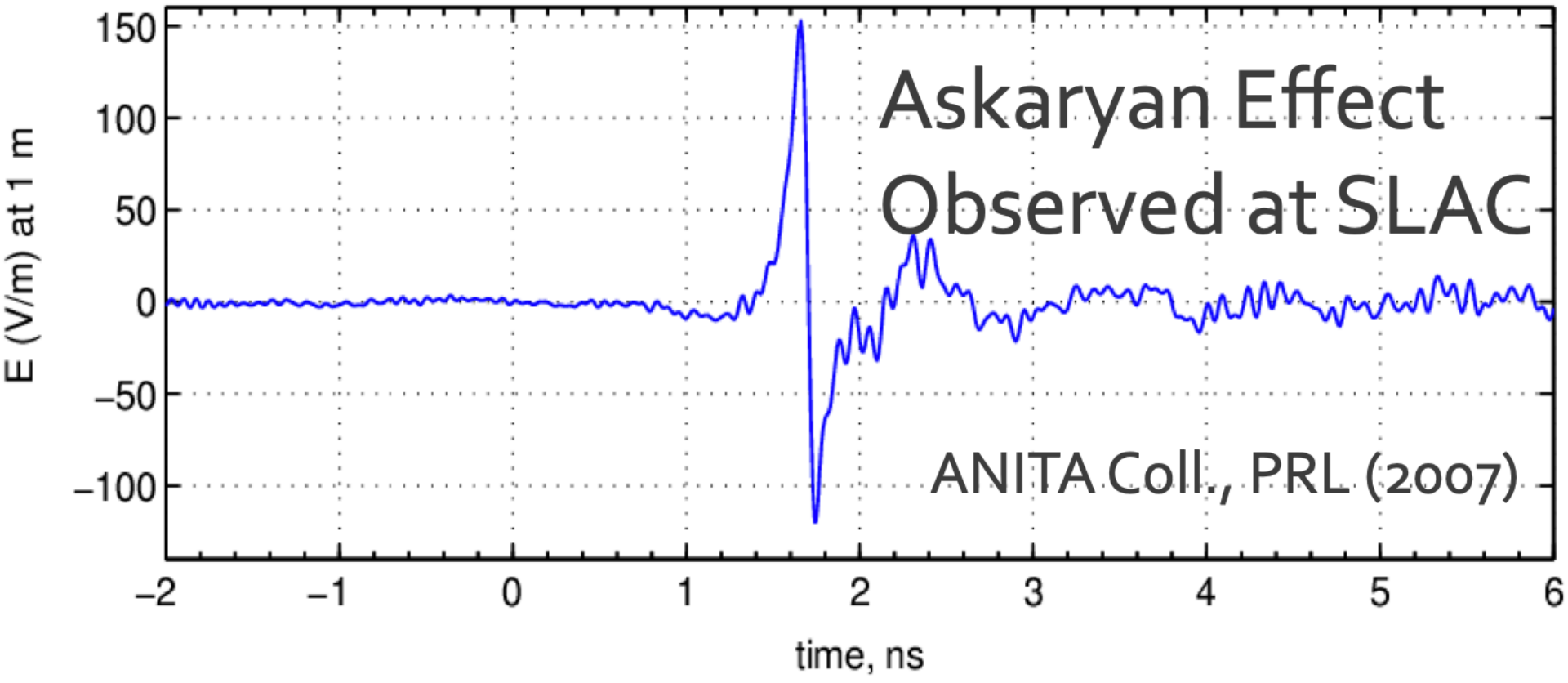
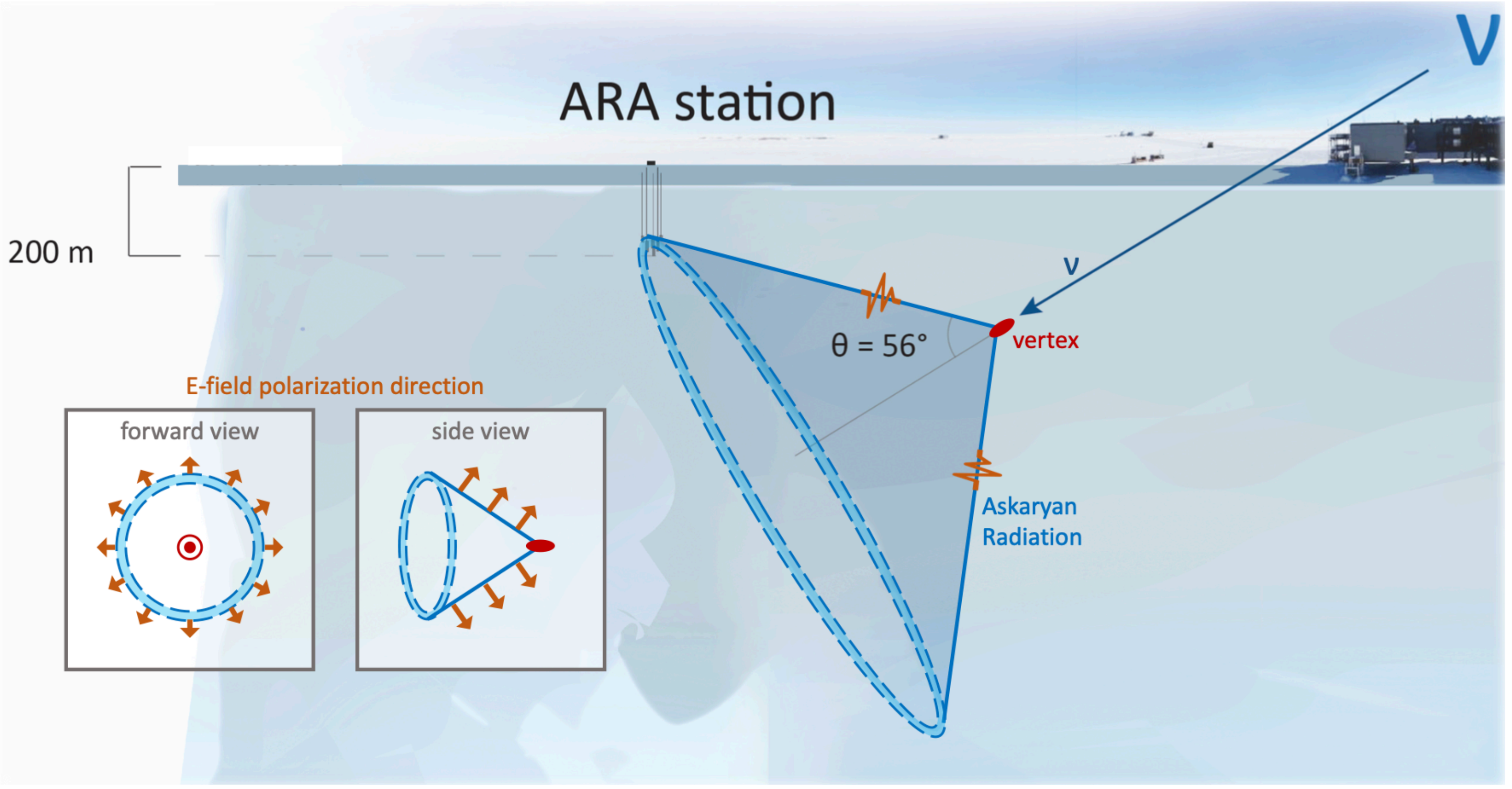
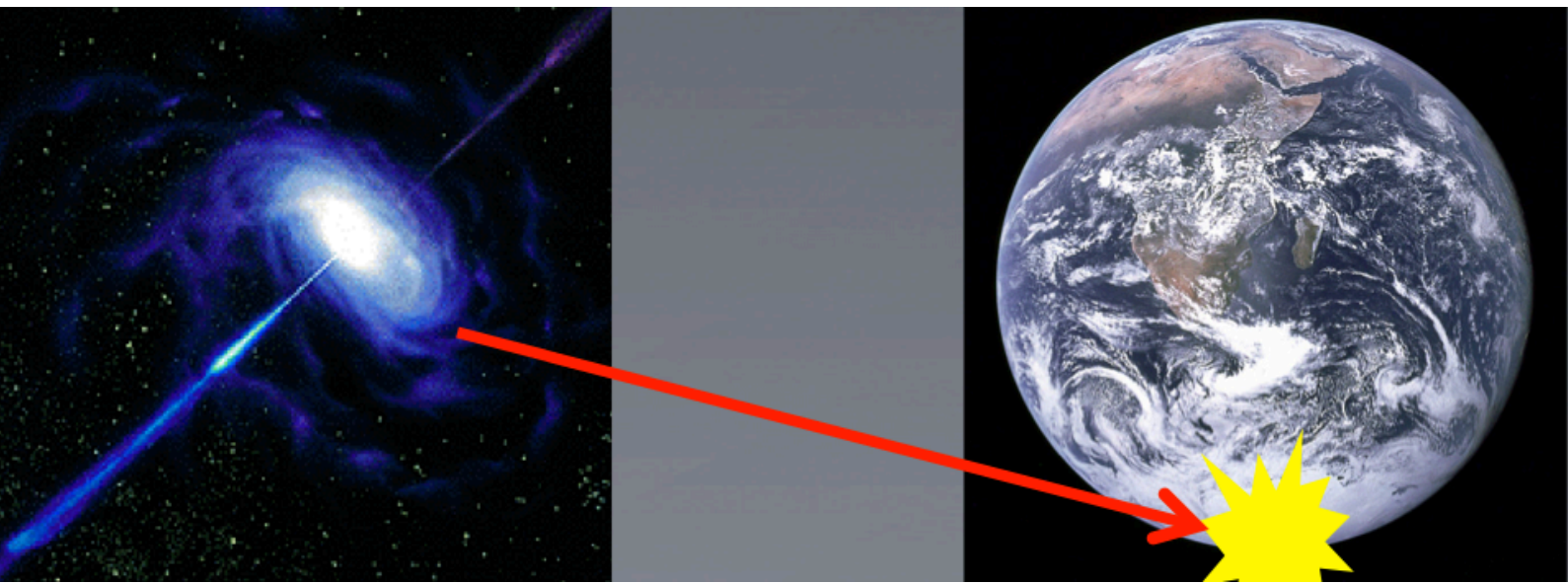
**Ideal Messenger for
Astro-Particle physics**

How ?



How to detect ultra high energy neutrinos ?

Askaryan radio signals in ice



Power $\sim E^2$ in radio component

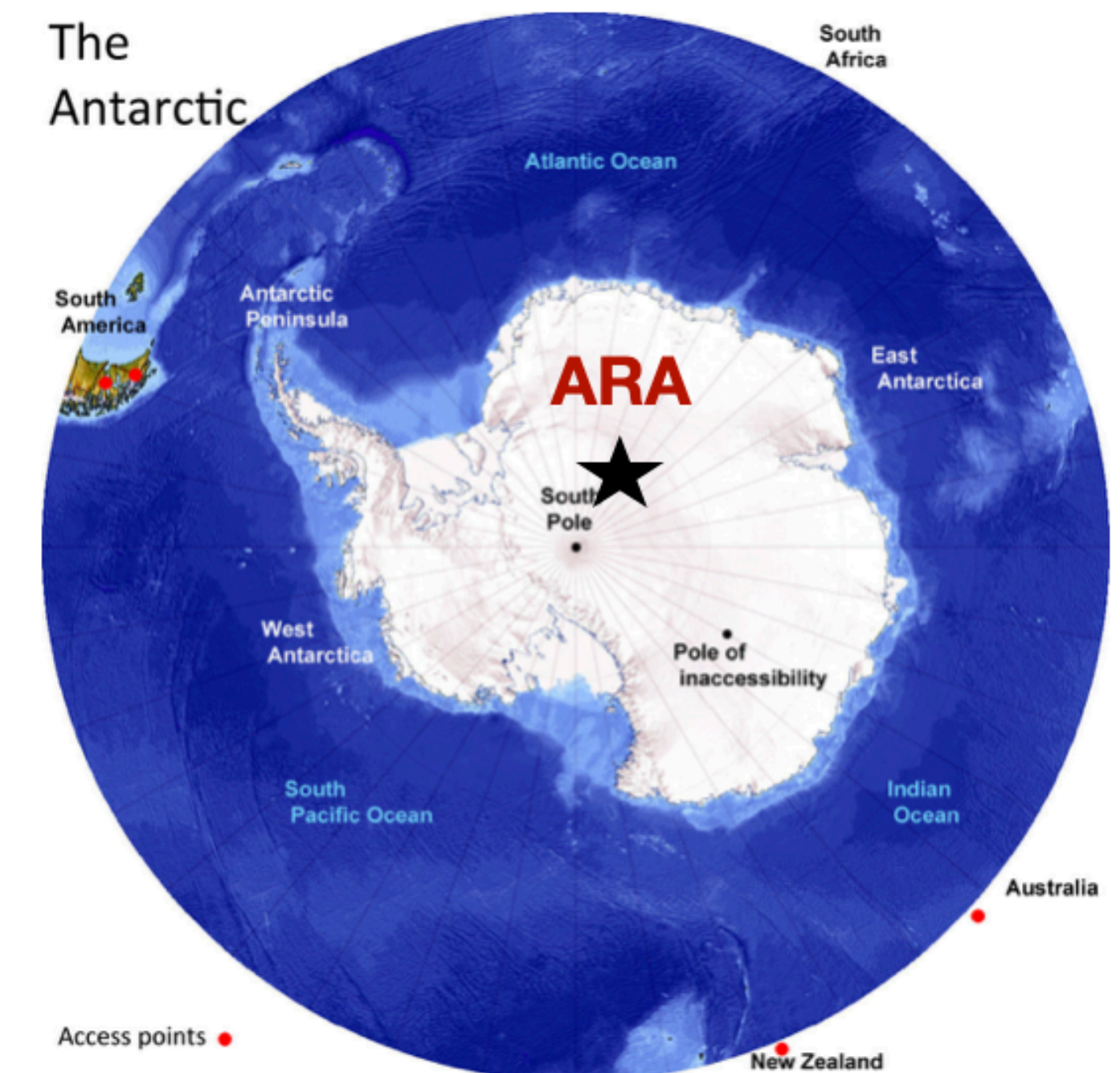
What kind of experiment we need?

- **0.003 GZK neutrinos/km³/year**
- **To get 1 GZK neutrinos we need > 1000 km³ of clean, dense dielectric medium**

Ice is an excellent radio transparent medium,

Long Radio attenuation length in ice (~ 1 km)

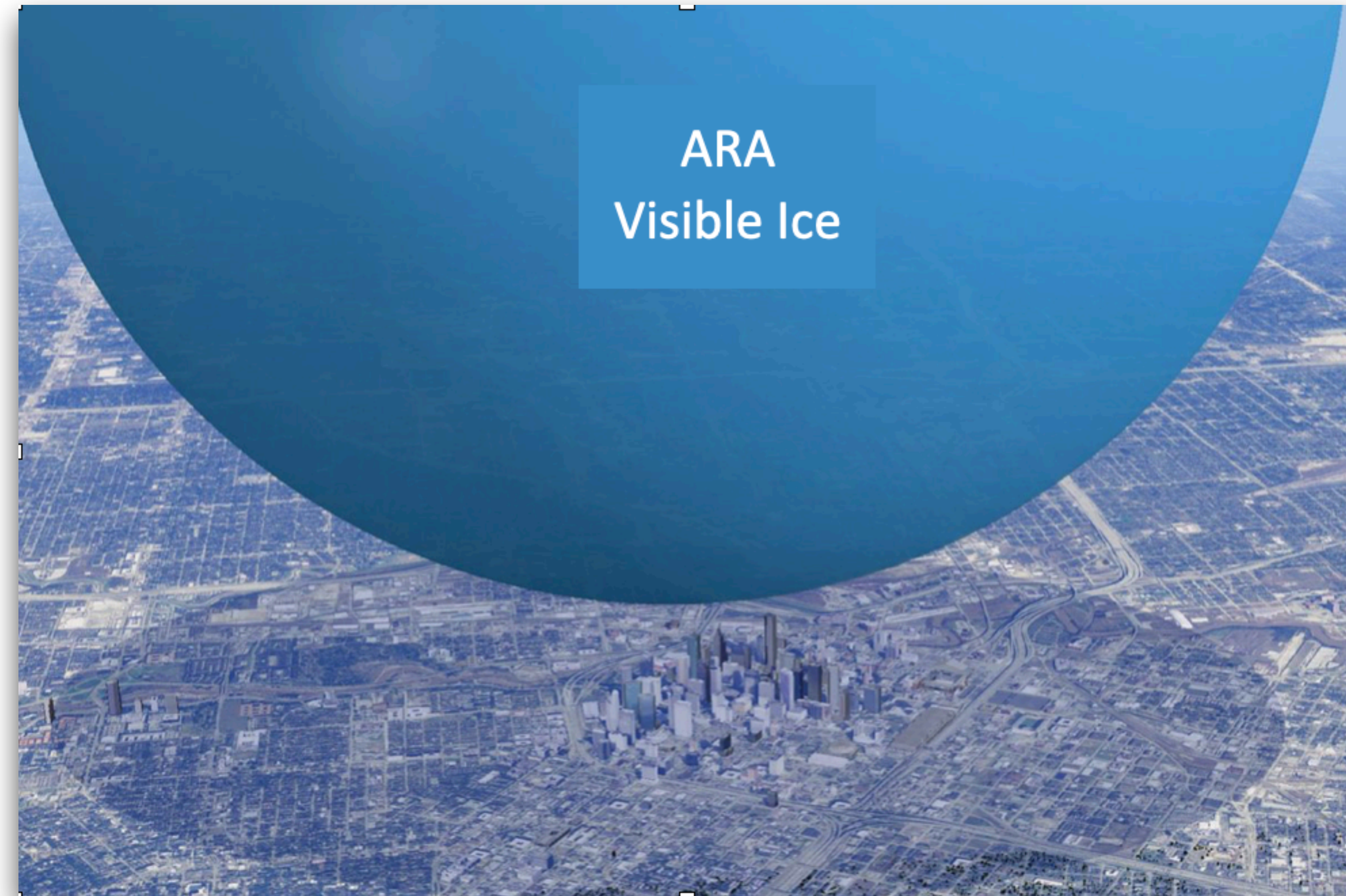
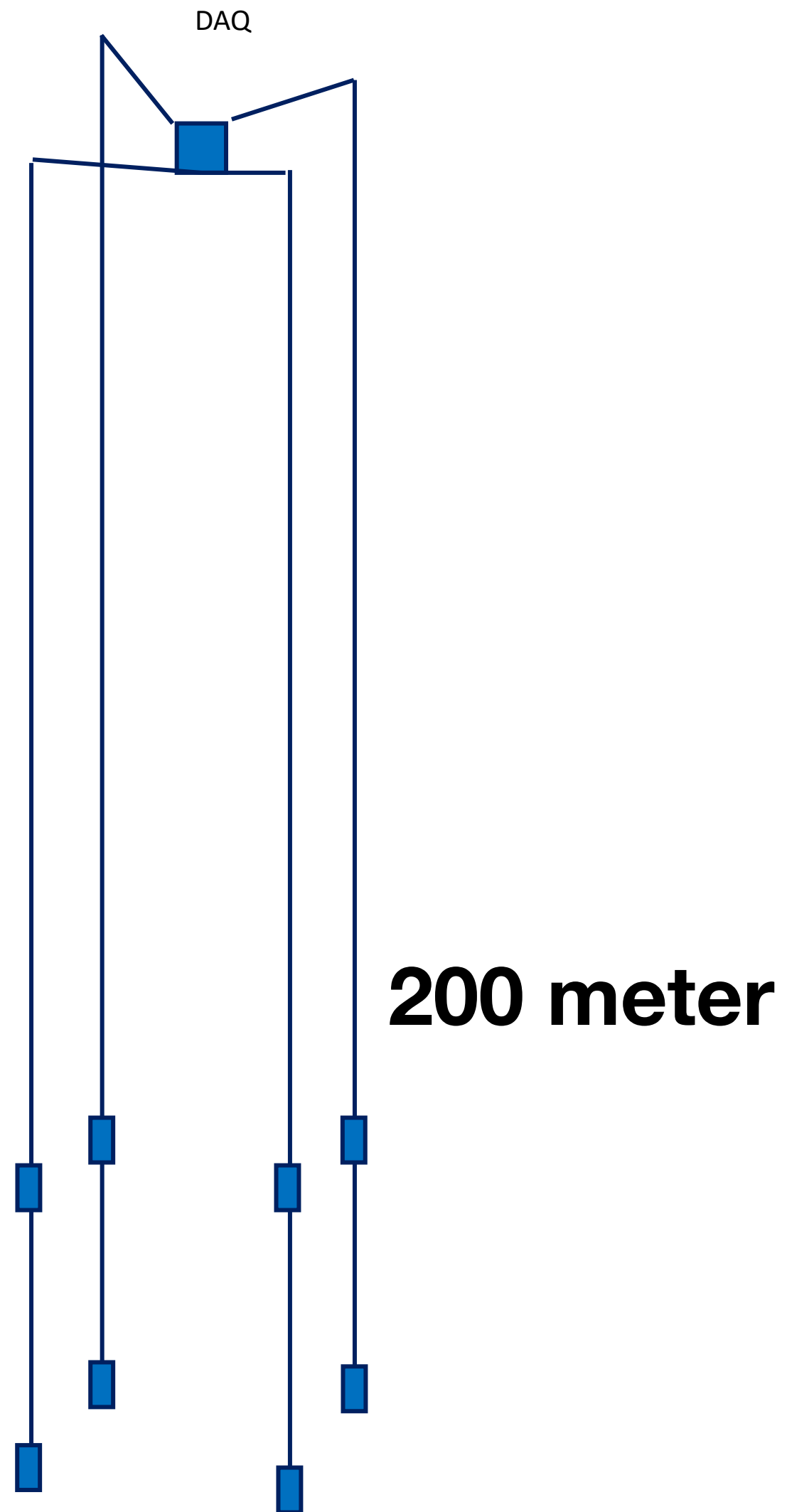
(vs. ~ 100 meter for optical signal, used by IceCube)



Enormous Volume to detect neutrinos

Depth of ARA antennas ~ 2.2 times the height of the Statue of Liberty

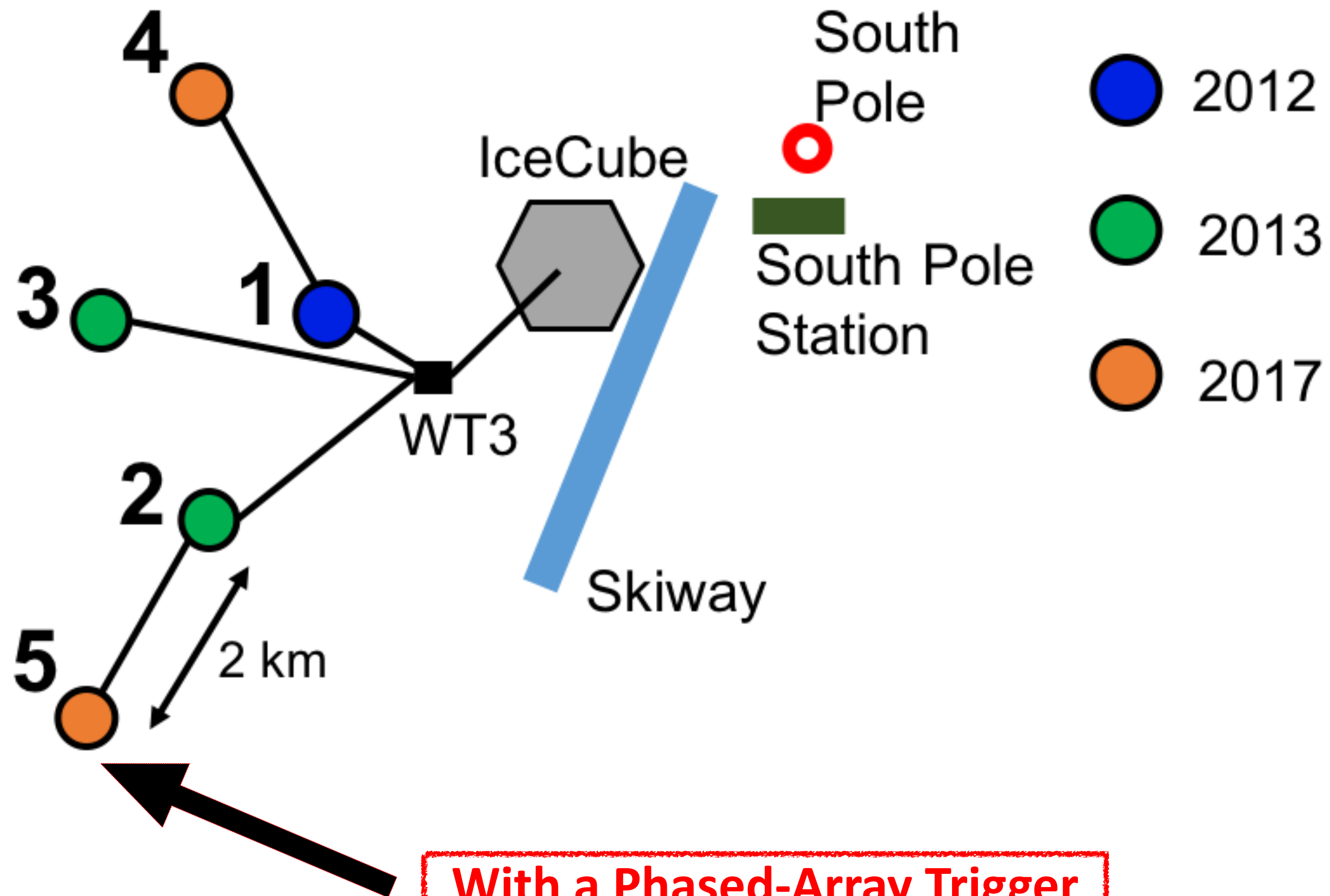
93 meter



1 ARA station ~ 20 km³ ice

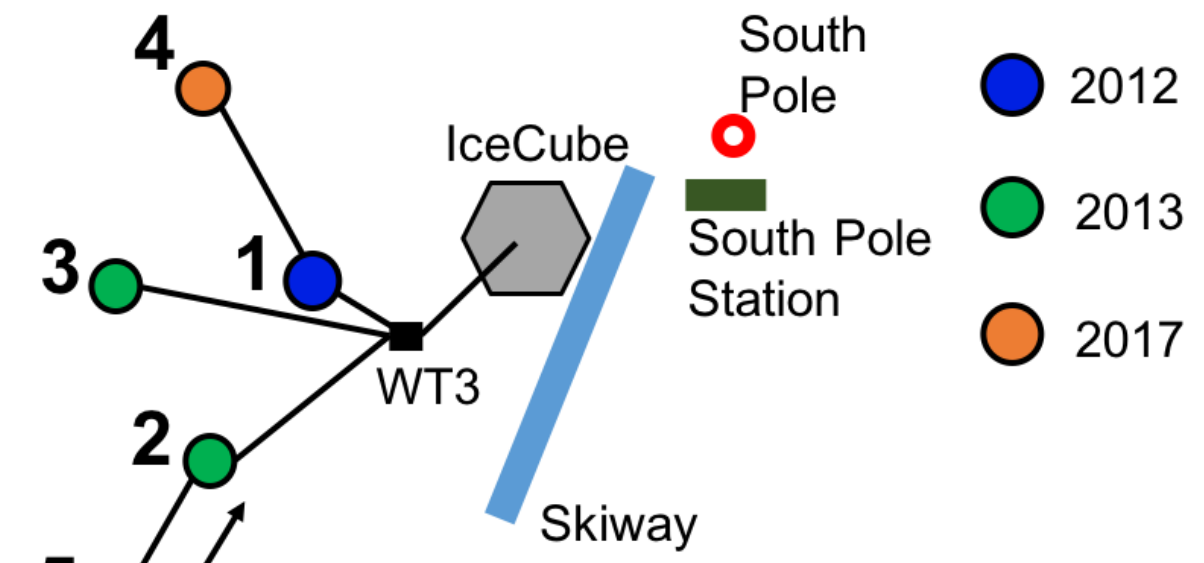
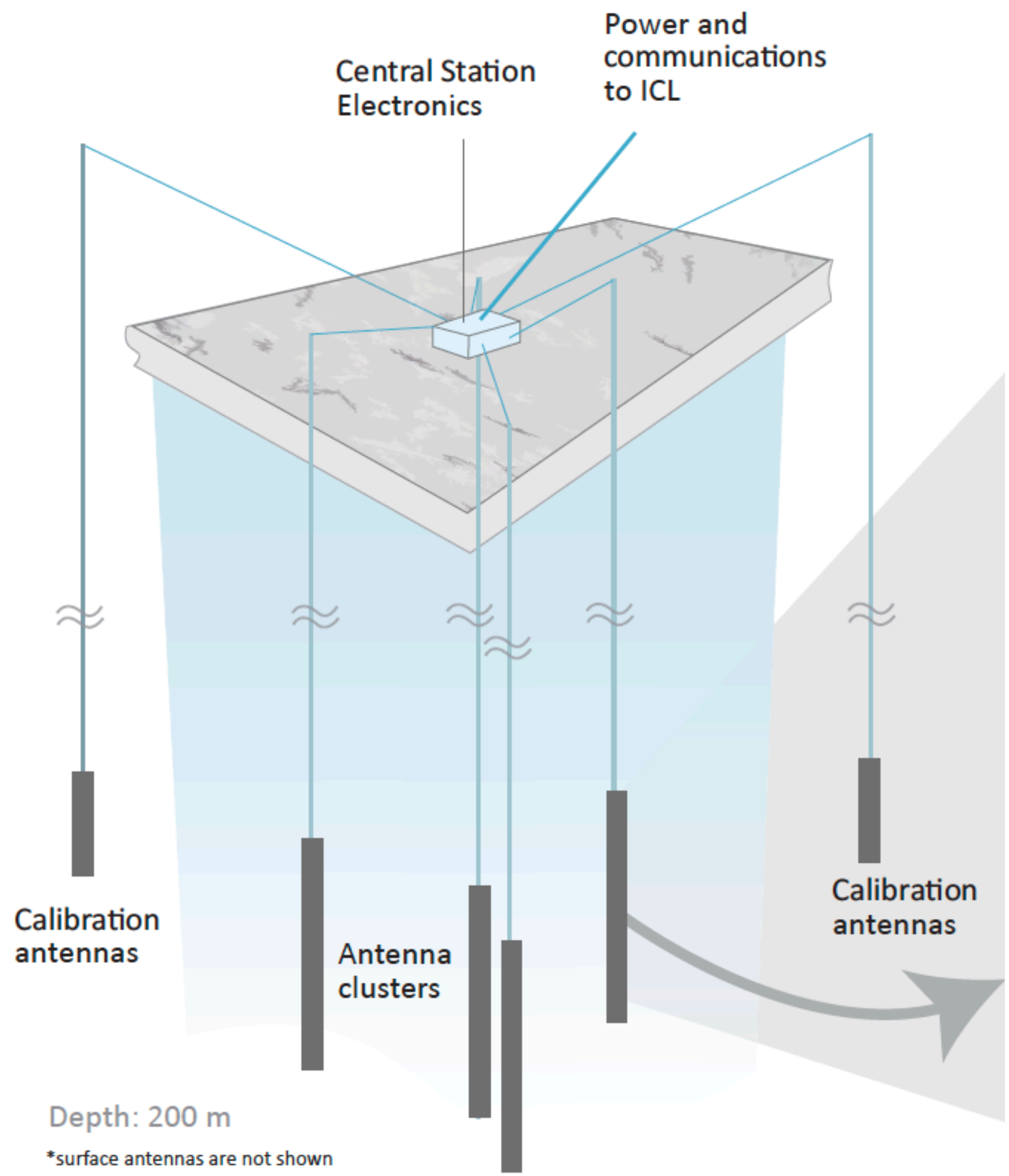
ARA detectors

Five independent stations have been collecting data for ~ a decade



ARA's 5th station is special

A1 - A4

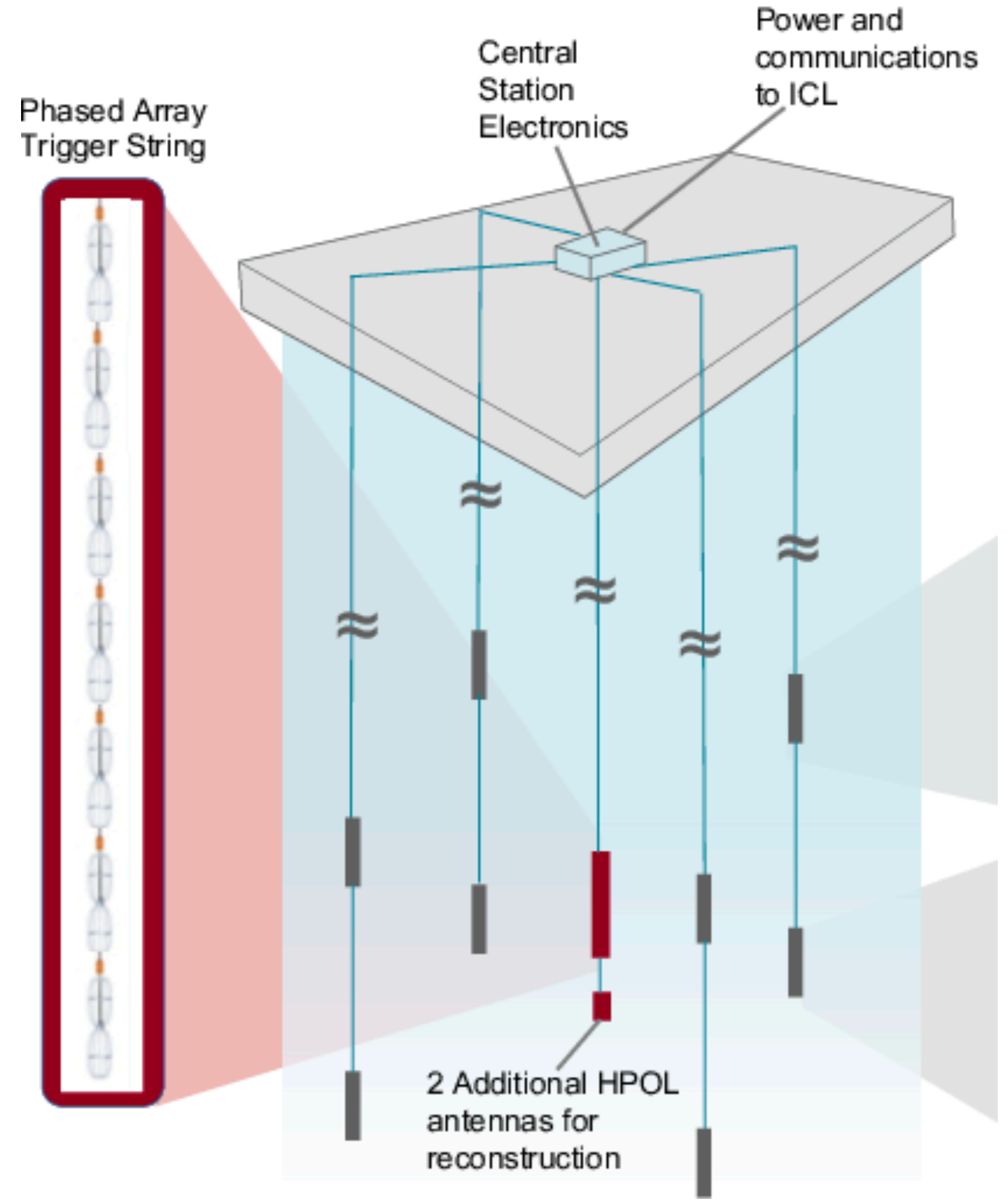


HPol



VPol

A5 + PA system



Status of UHE neutrino searches with ARA data

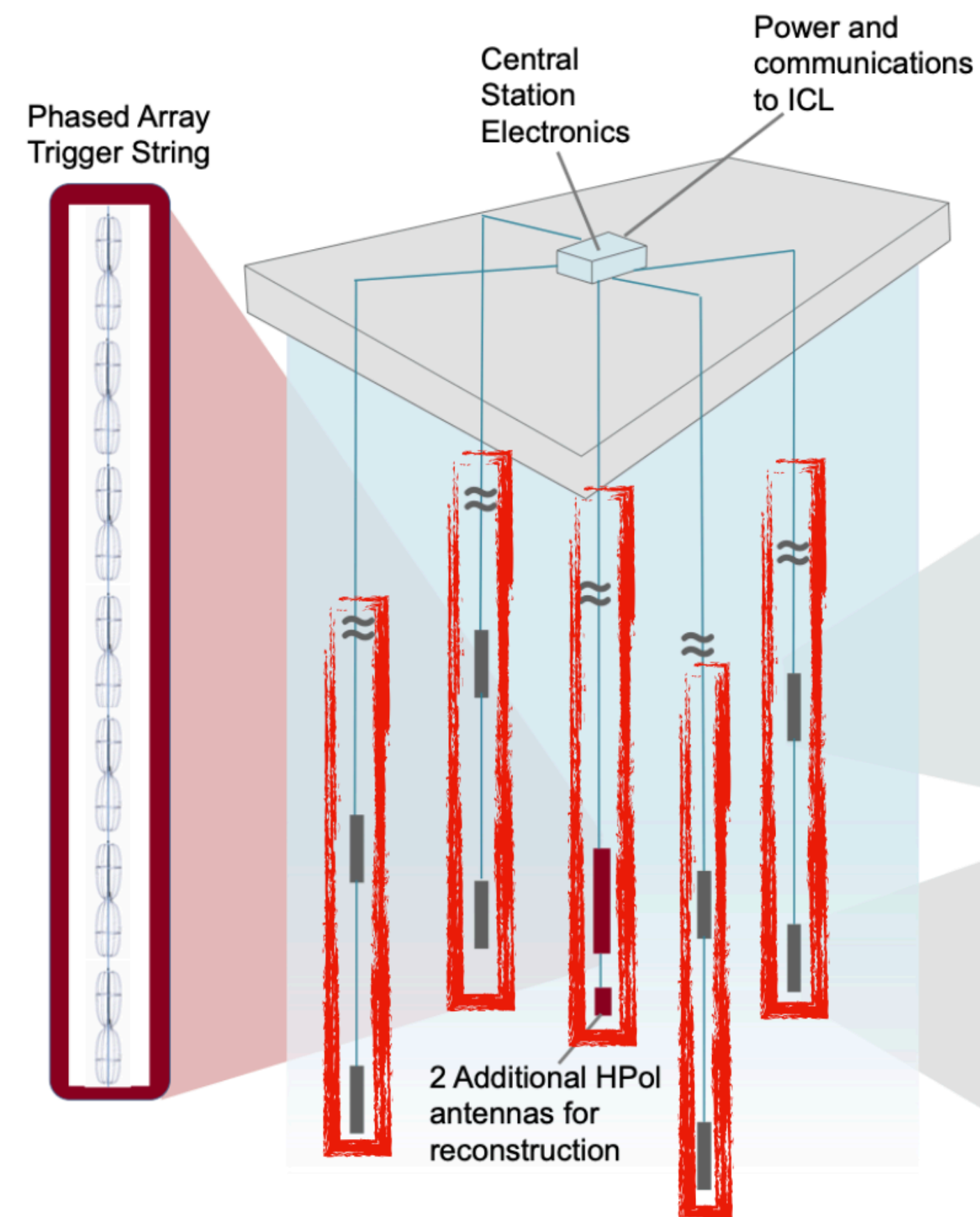
- **ARA collaboration is performing two analyses:**
 - **Highly-coordinated, multi-institution analysis with full array**
 - **A pioneering analysis that will lead next-generation of experiments.**

A Pioneering Hybrid Analysis

Combine PA & ARA subdetectors to maximize background rejection & analysis efficiency

- **Hybrid design = Phased array + 7 A5 Vpols** readout through the Phased Array DAQ
- **Unique detector, representative of next generation of detectors like RNO-G & IceCube-Gen2**
- **Livetime : 2020 + 2021 data from hybrid system**
- **Optimize cuts for 5σ discovery potential**

ARA station 5



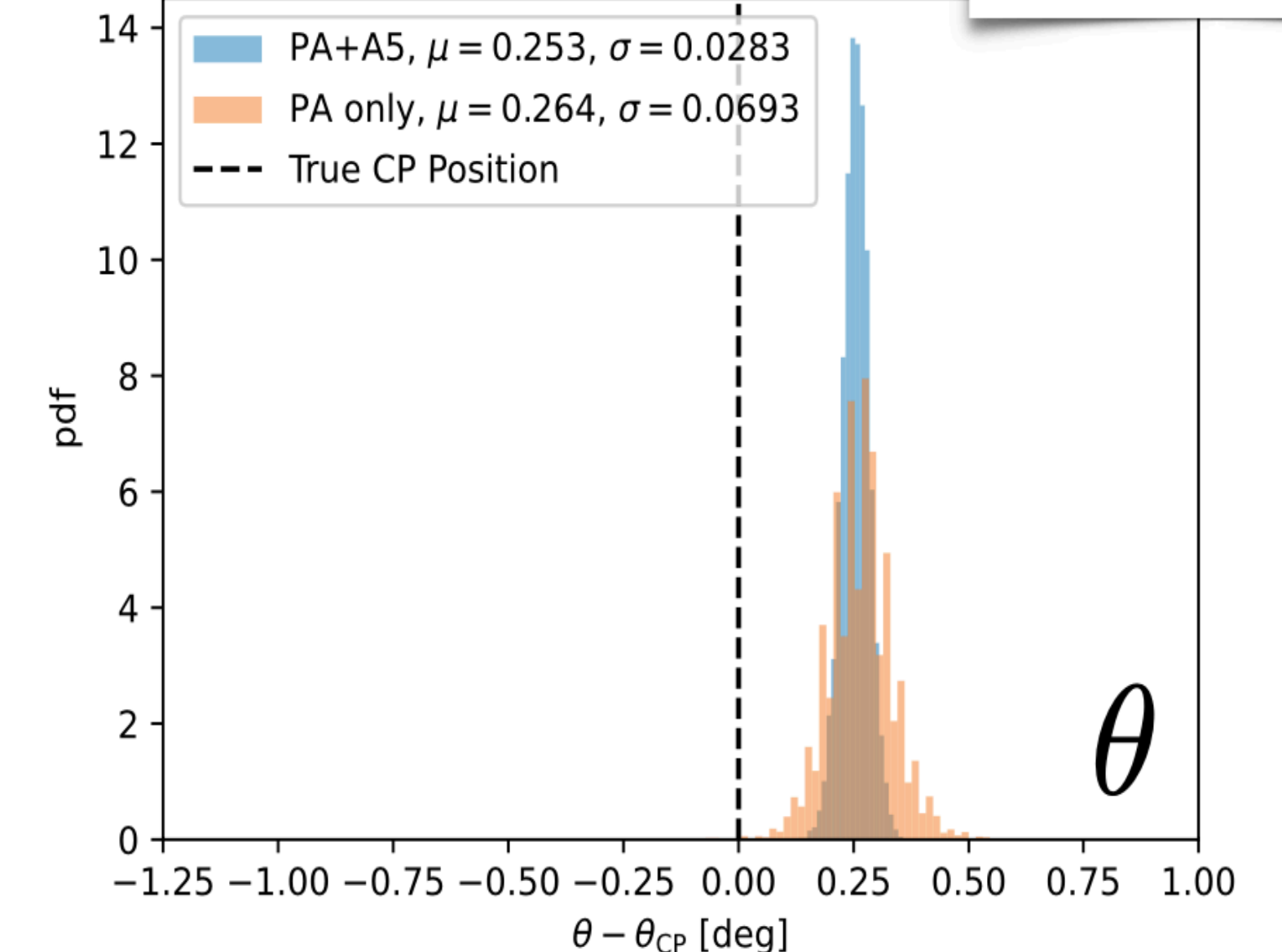
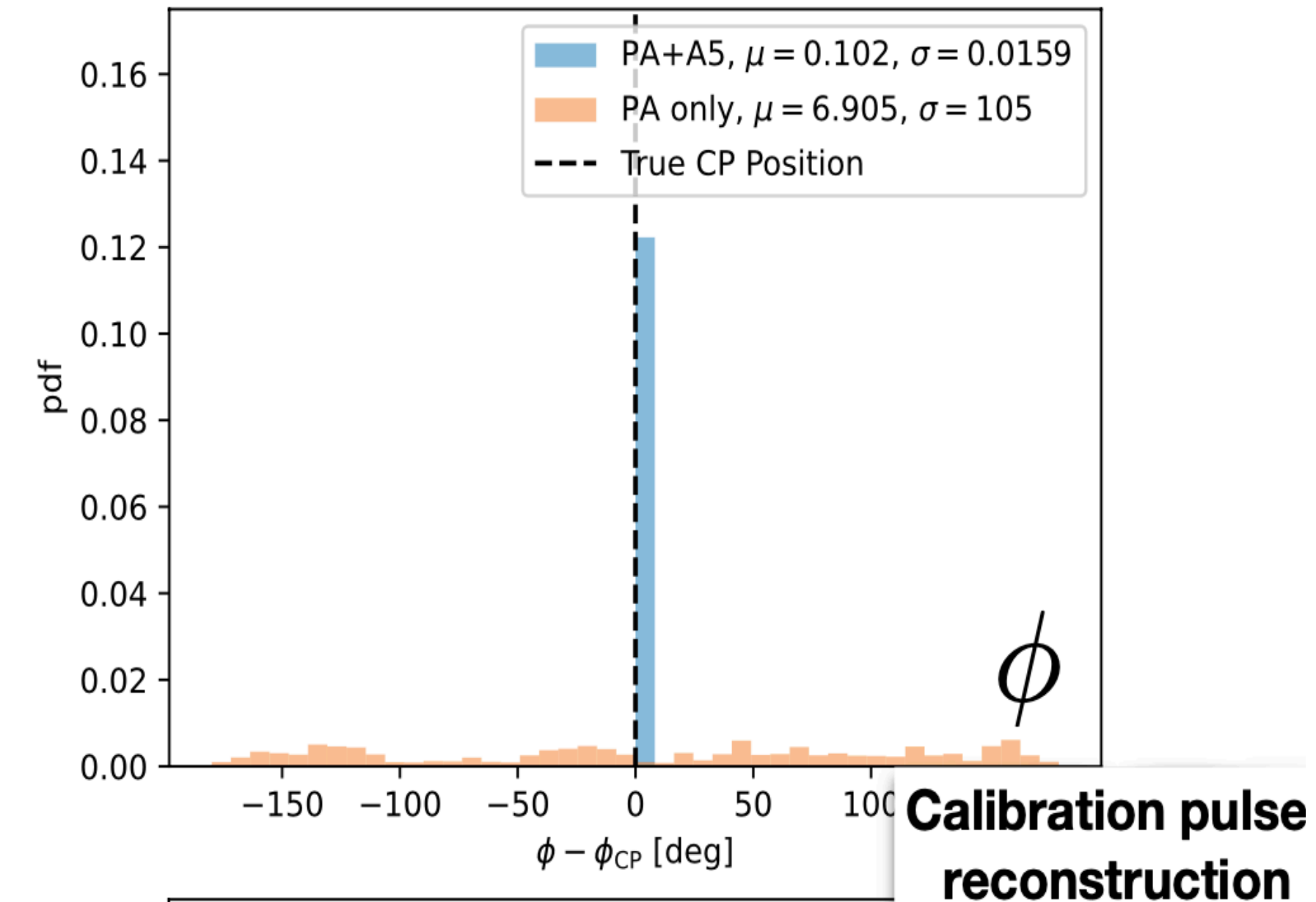
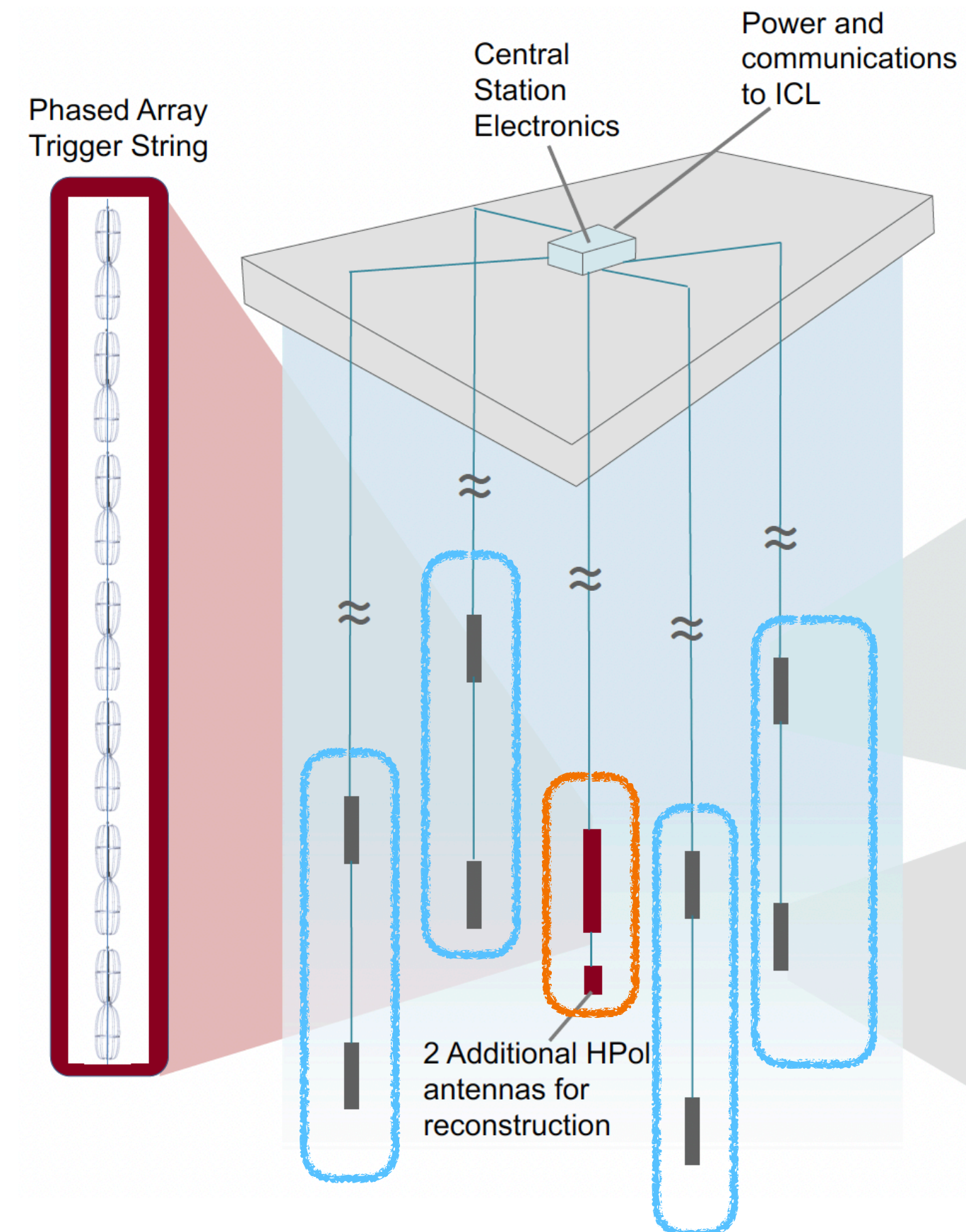
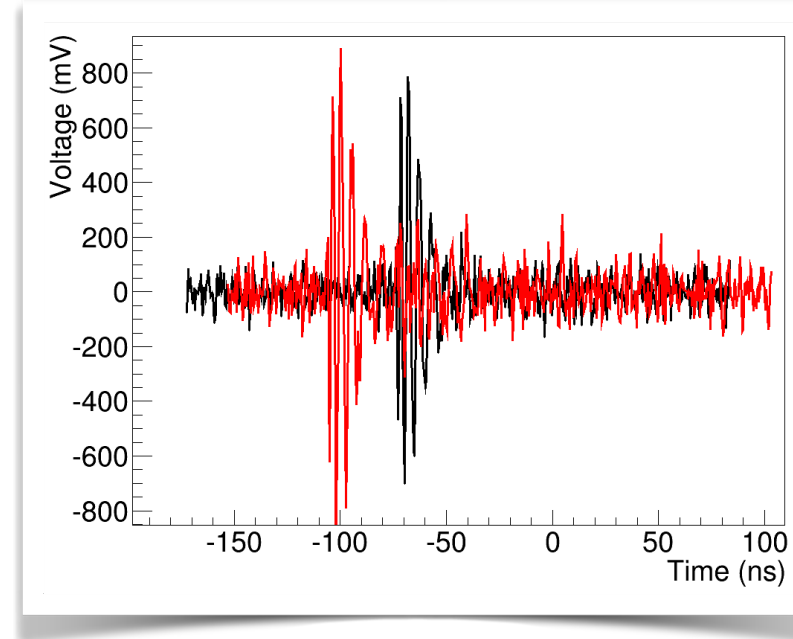
Paramita Dasgupta, Ohio State



Marco Muzio, Penn State

Advantages of a Hybrid detector

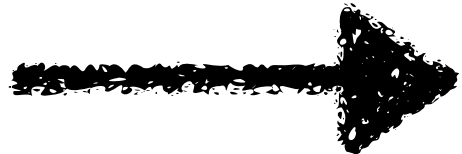
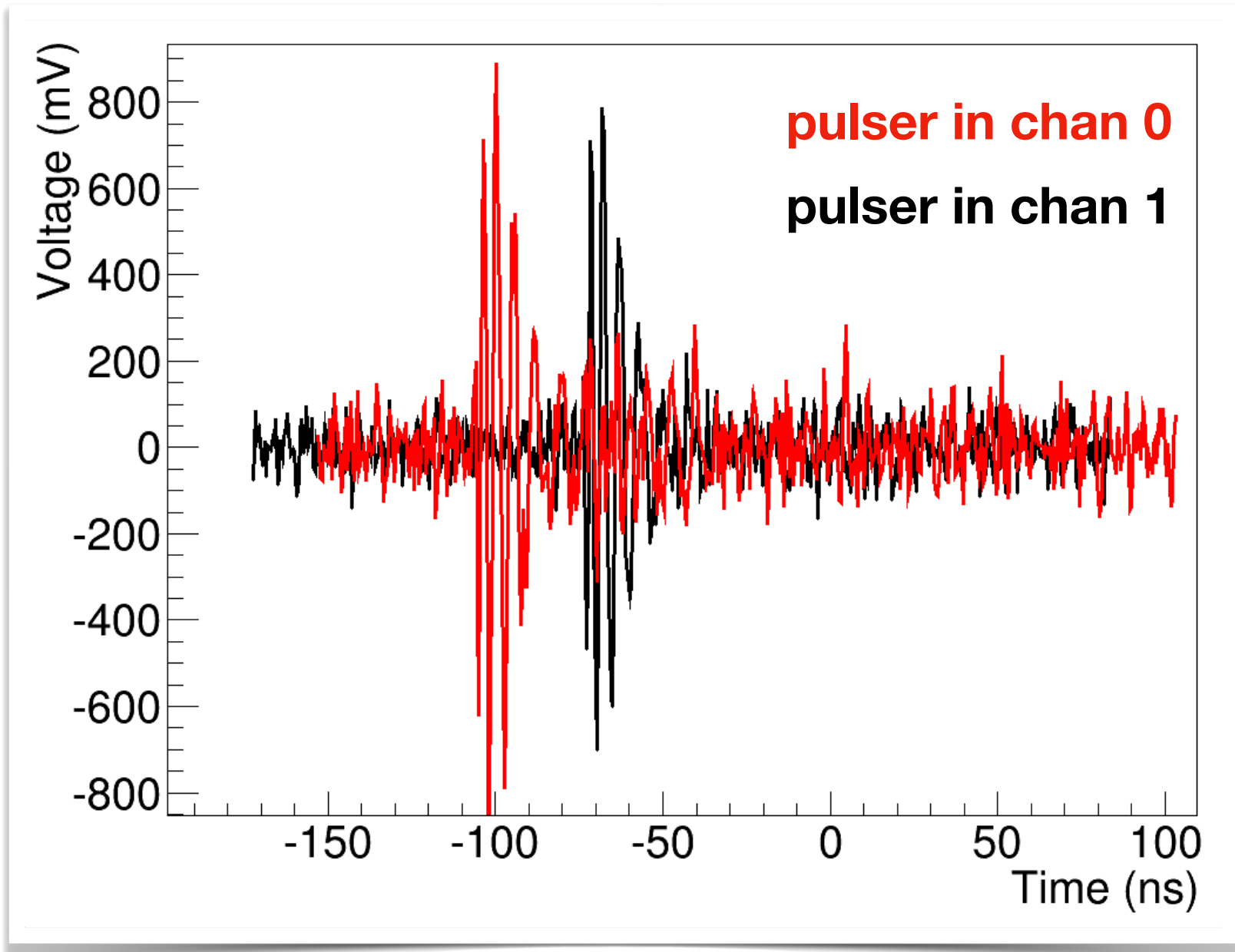
- **Excellent azimuth sensitivity with hybrid antennas**
- **~2x zenith sensitivity to vertex position**
- **Precise in-ice reconstruction of events**
- **High background rejection based on direction and timing information**



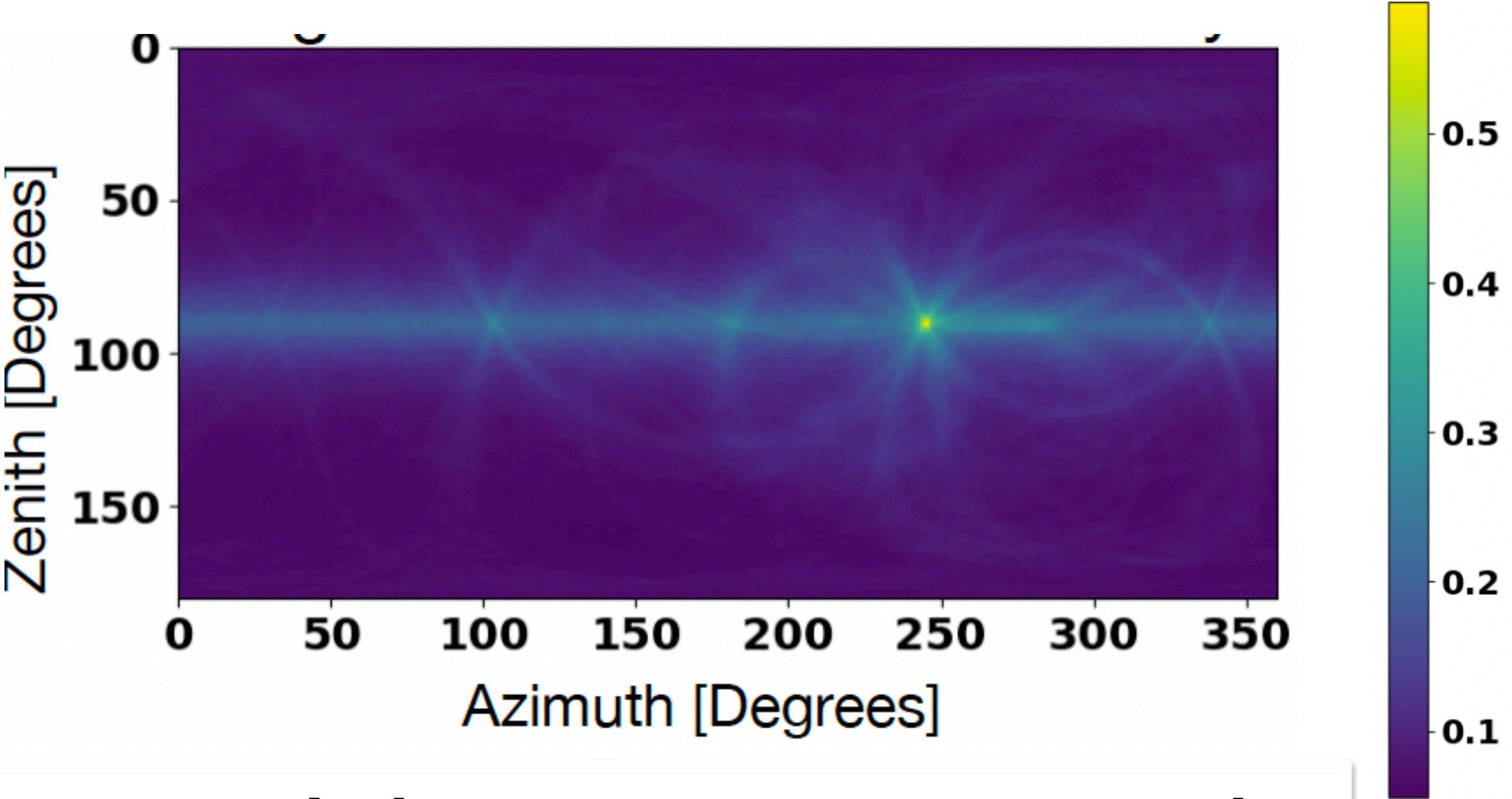
Reconstruction of Source location with A5-PA hybrid system

- Excellent pointing accuracy with A5-PA antennas, improved vertex reconstruction would lead to improved analysis efficiency
- Improved surface background removal using correlation map

Pulsar signal in a pair of channels

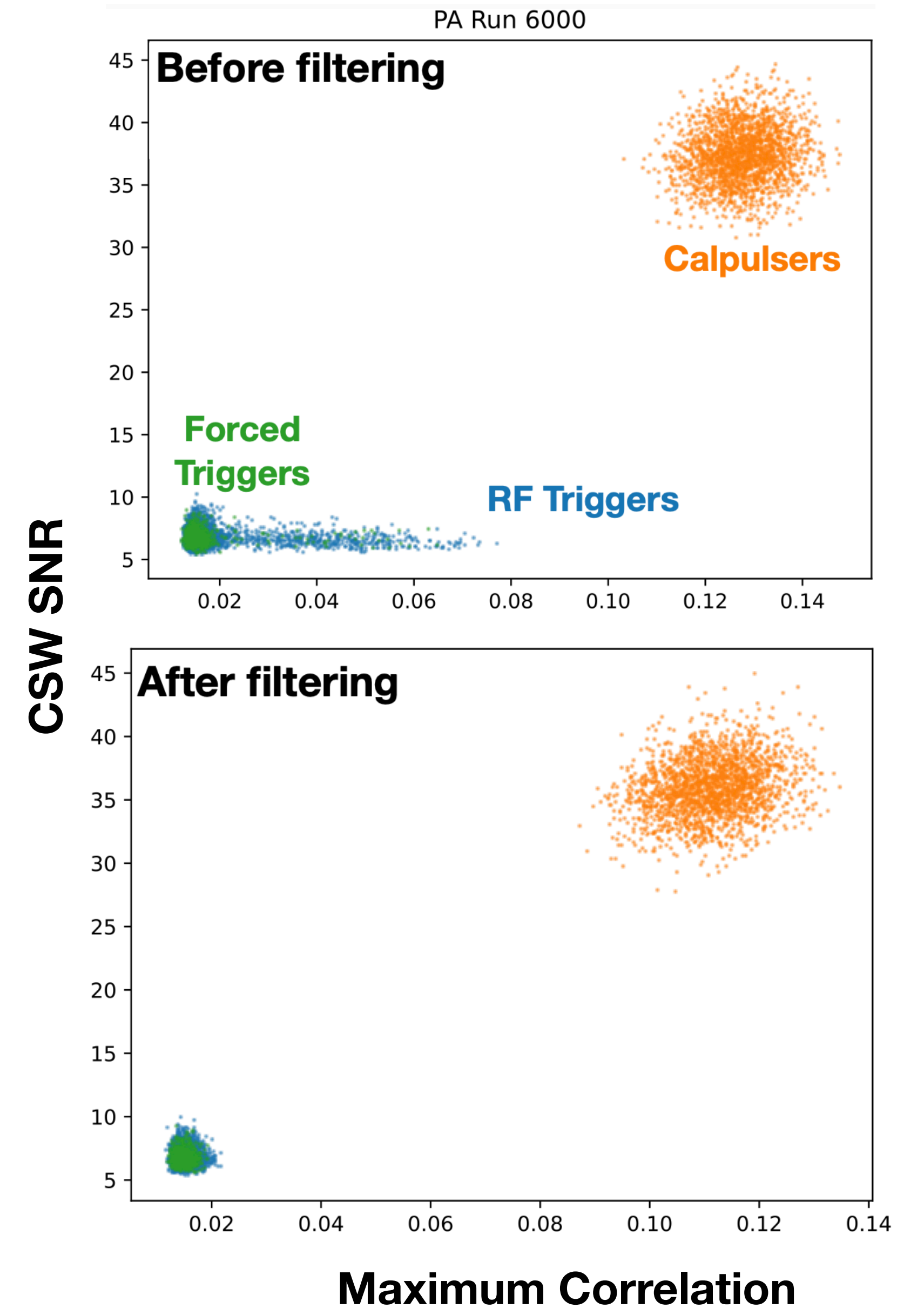
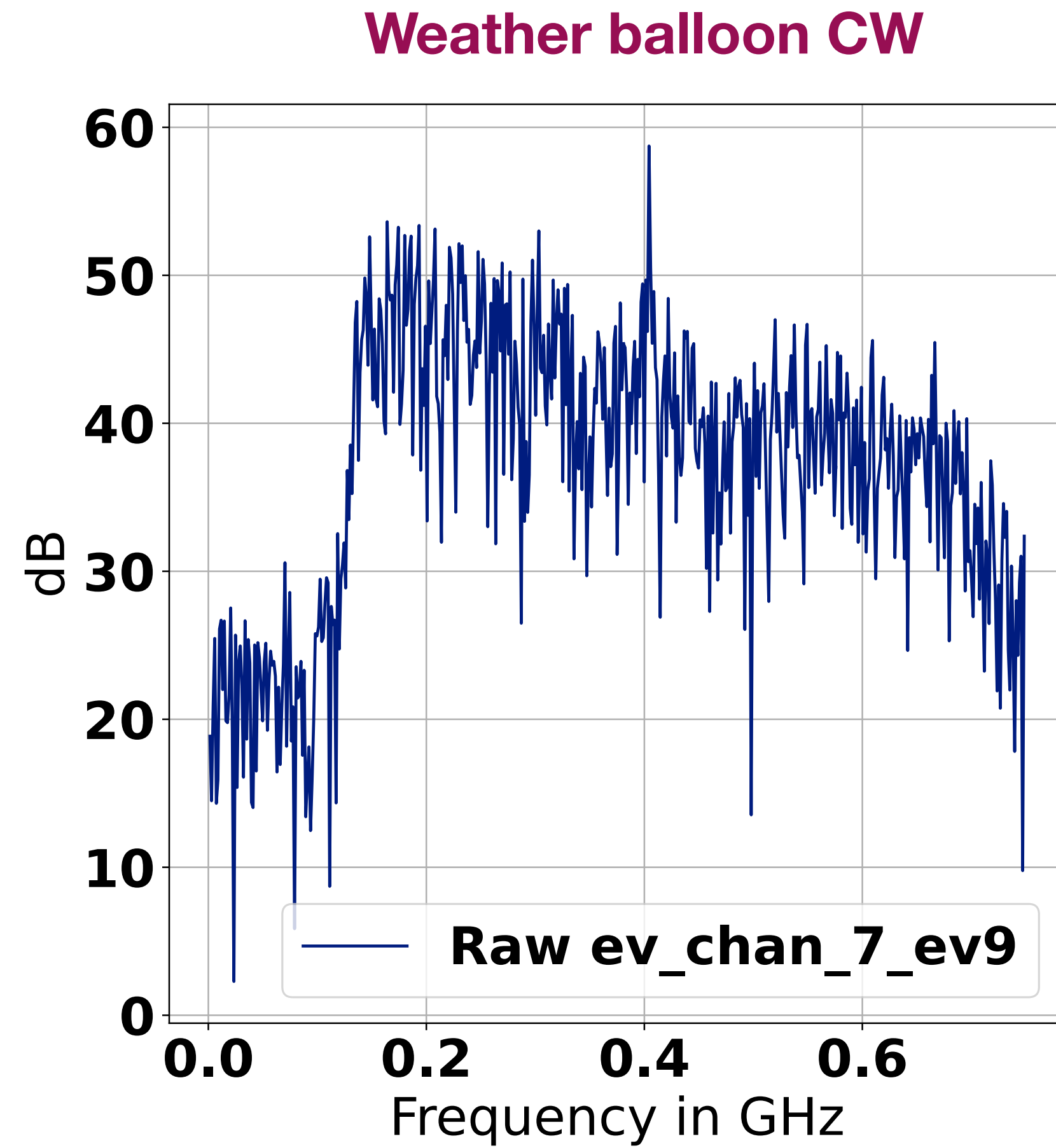


Reconstructed pulsar source location using A5-PA hybrid antennas

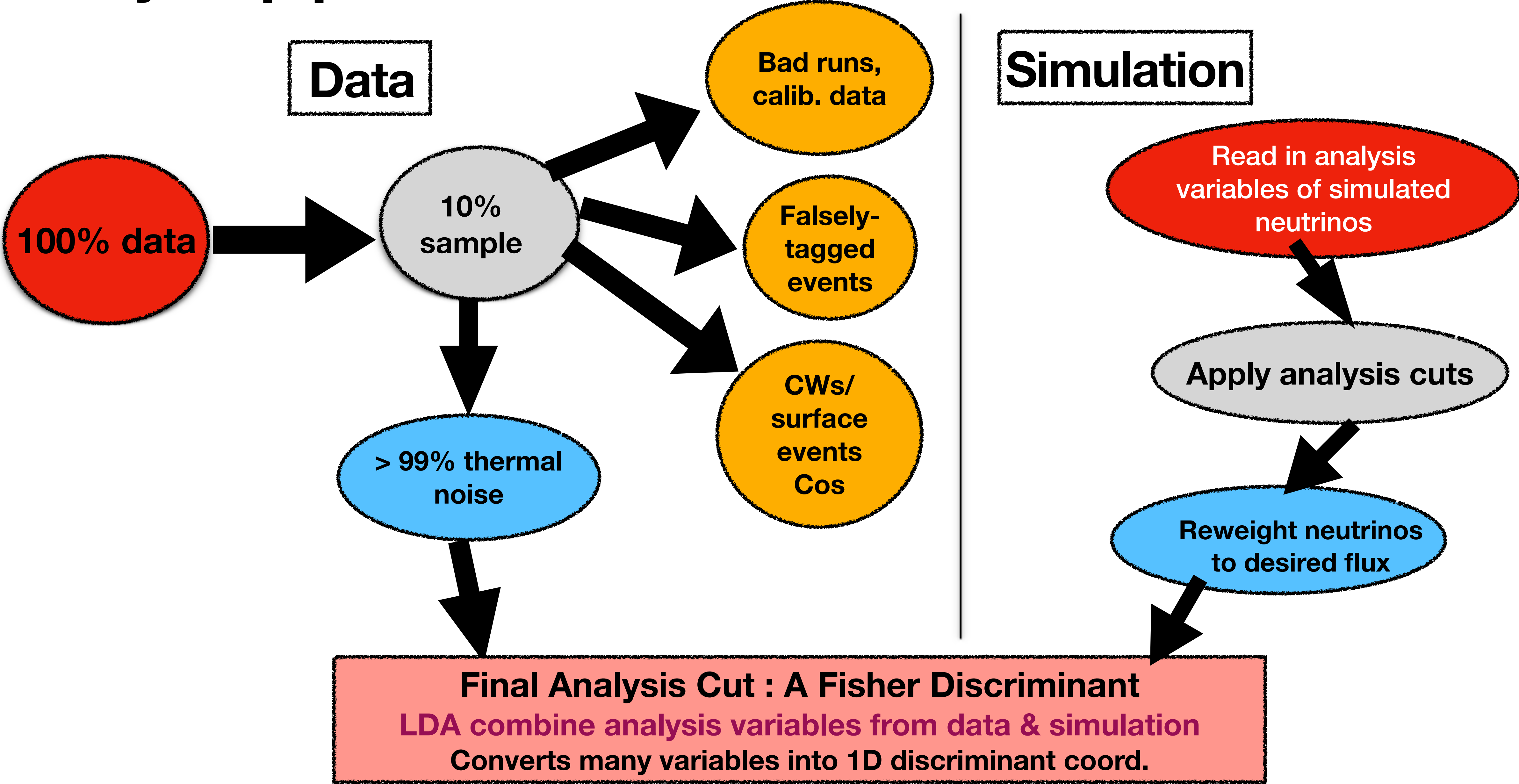


< 1 degree resolution on vertex reconstruction

Background removal: Continuous Wave (CW) Signals



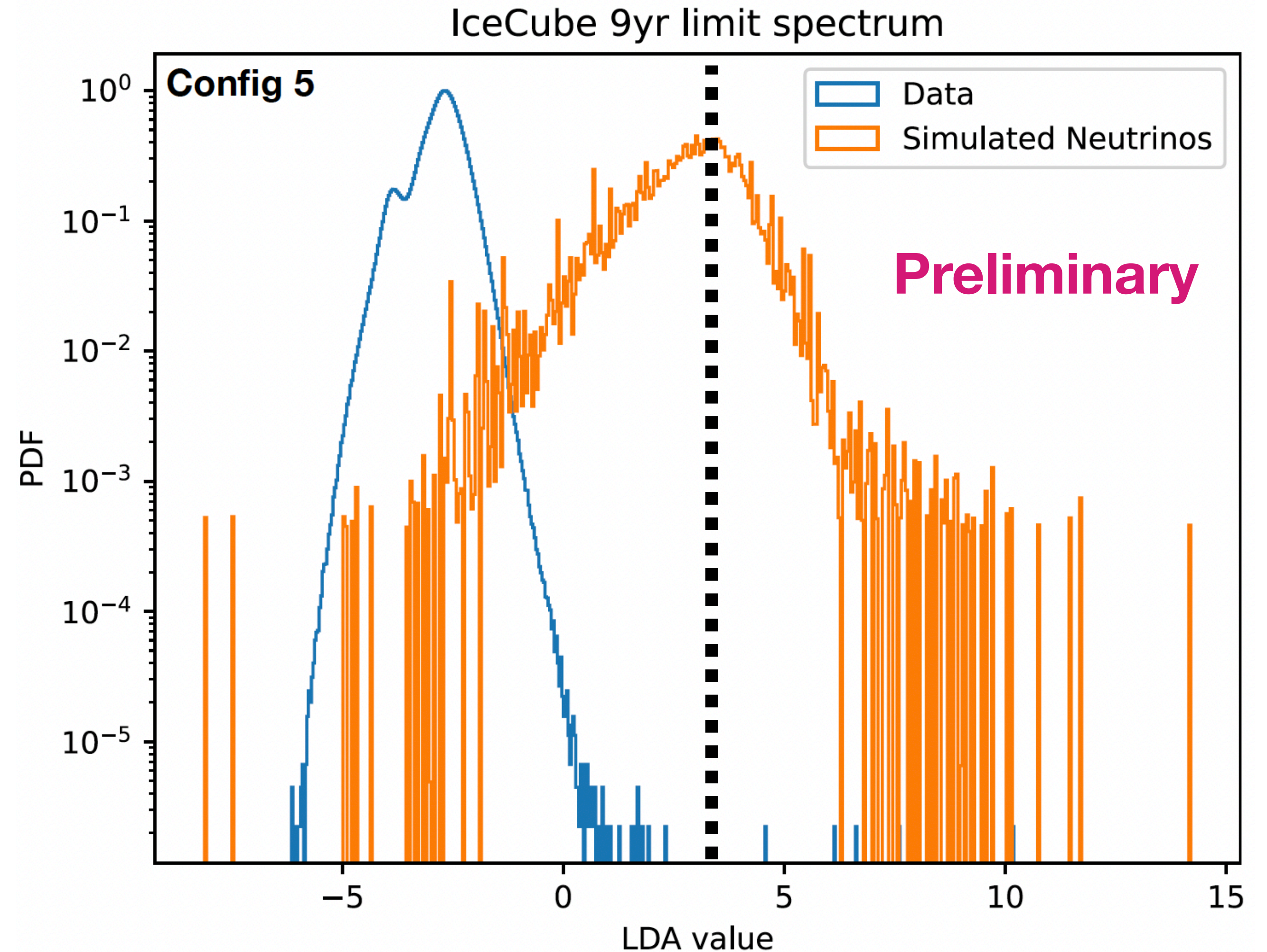
Analysis pipeline



Separating Thermal Noise from Signal: Fisher Discriminant

We are setting a cut for the best expected sensitivity.

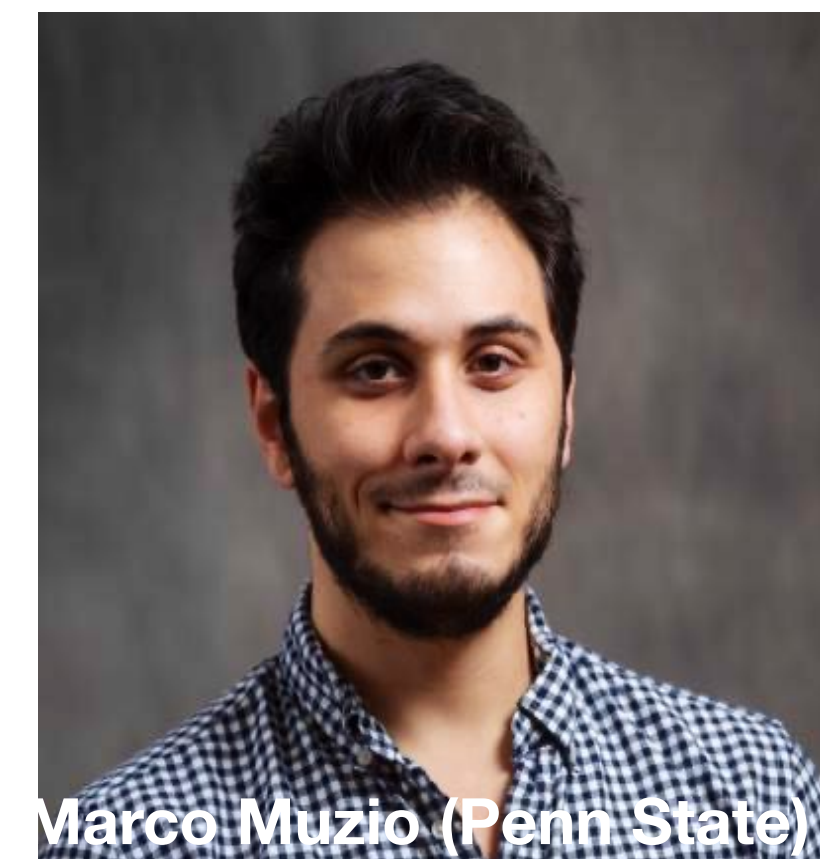
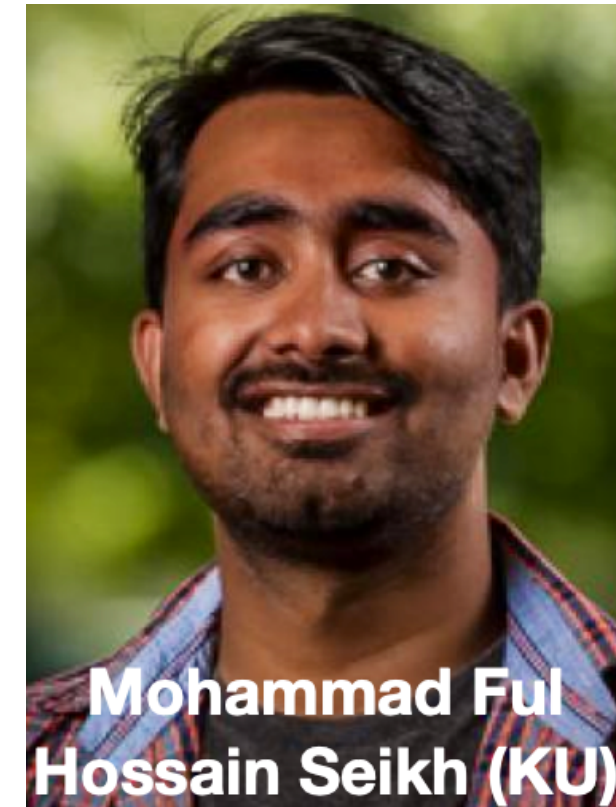
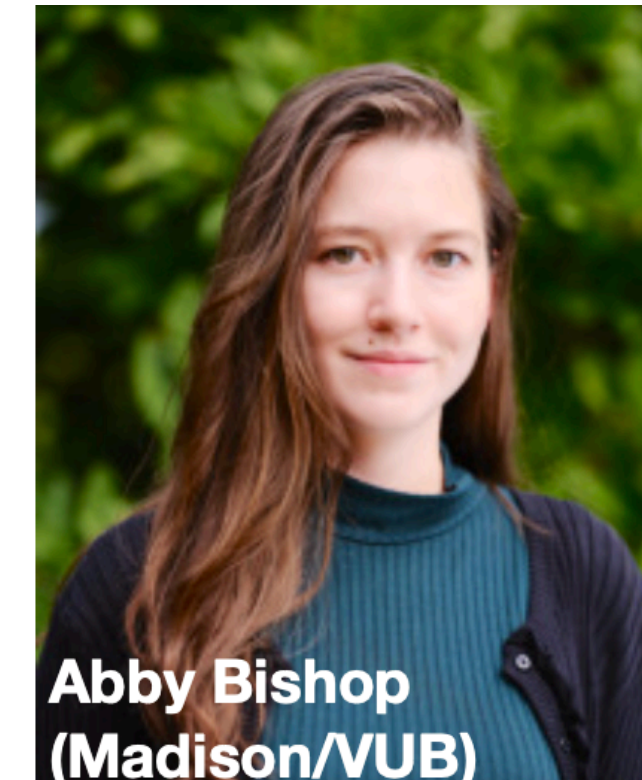
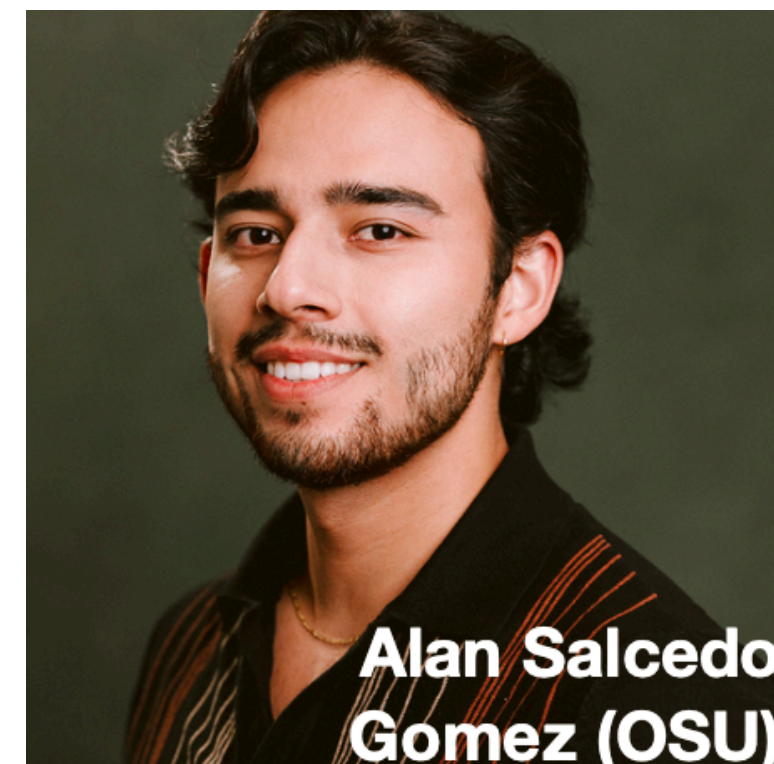
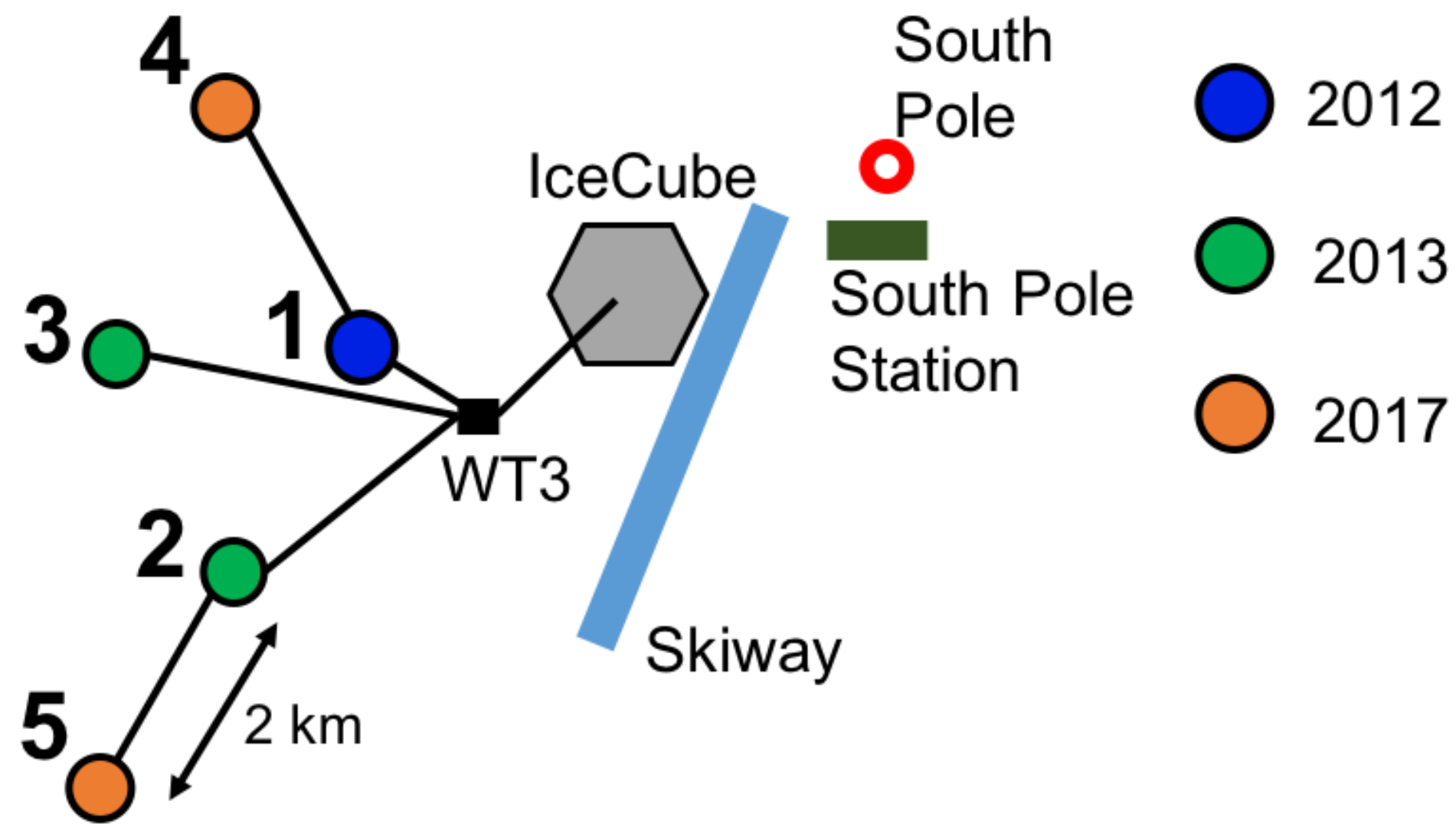
Cut will be optimized for 5σ discovery using IceCube 2018 flux limit



* Large fluctuations in simulated neutrino distribution due to limited statistics at low energies
additional simulations underway

Towards a Five Station Analysis

- ◆ Goal: Conduct diffuse neutrino search in livetime through 2023 leveraging the entire Askaryan Radio Array
- ◆ Roughly 379 TB of data on disk



First array-wide search in deep stations

Paramita Dasgupta, CCAPP, Ohio State Univ.

Summary

❖ ARA is running since 2012. We have enormous amount of data on disk.

❖ We are conducting 2 analyses with ARA data

1. **Pioneering analysis with a low threshold neutrino search:**

- Proof of concept for next-generation large in-ice radio array RNO-G (35 stations) & IceCube-Gen2 Radio (361 stations)

2. **Highly-coordinated, multi-institution analysis with all 5 ARA stations' data**

These 2 analyses will yield either:

● **First UHE neutrino candidates !!**

● **Strongest flux limit up to 1000 EeV (10^{21} eV)
from any radio experiment to date !**



Thank you

