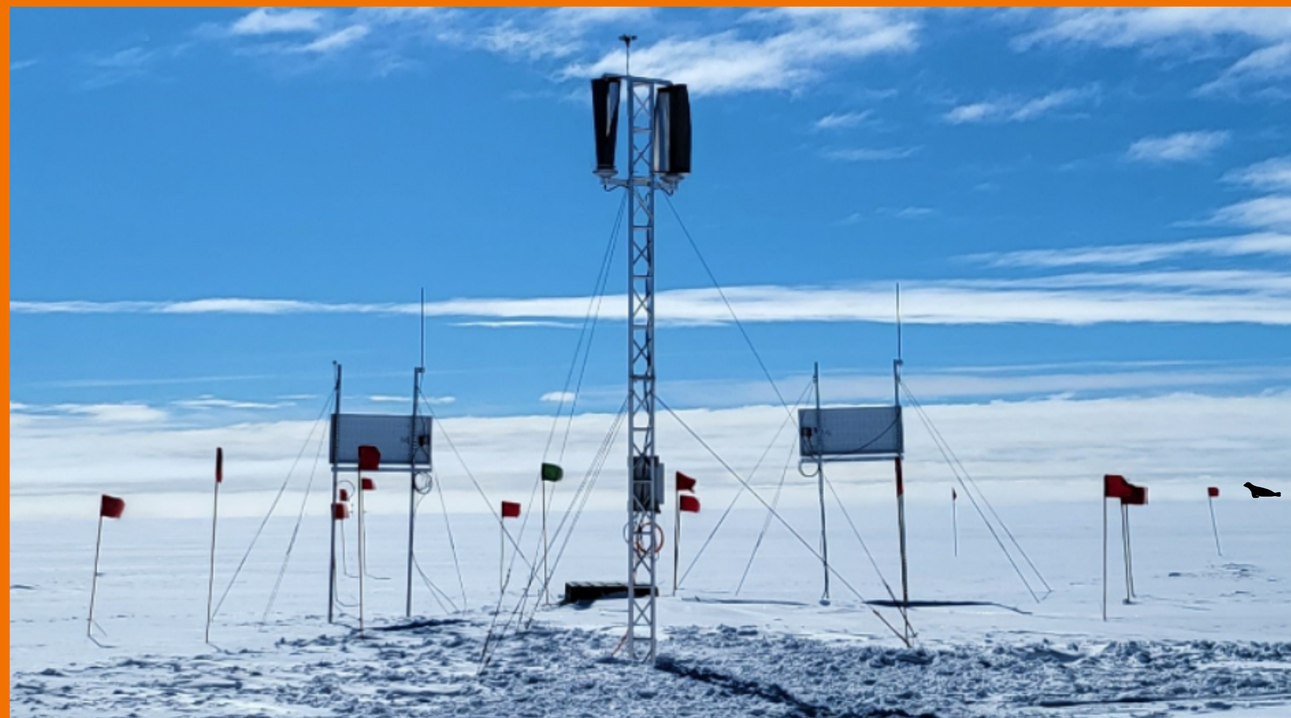
The Radio Neutrino Observatory - Greenland

Detecting ultra-high-energy neutrinos from the northern sky

Felix Schlüter - felix.schluter@icecube.wisc.edu

CosPa - Ghent , 19.06.23



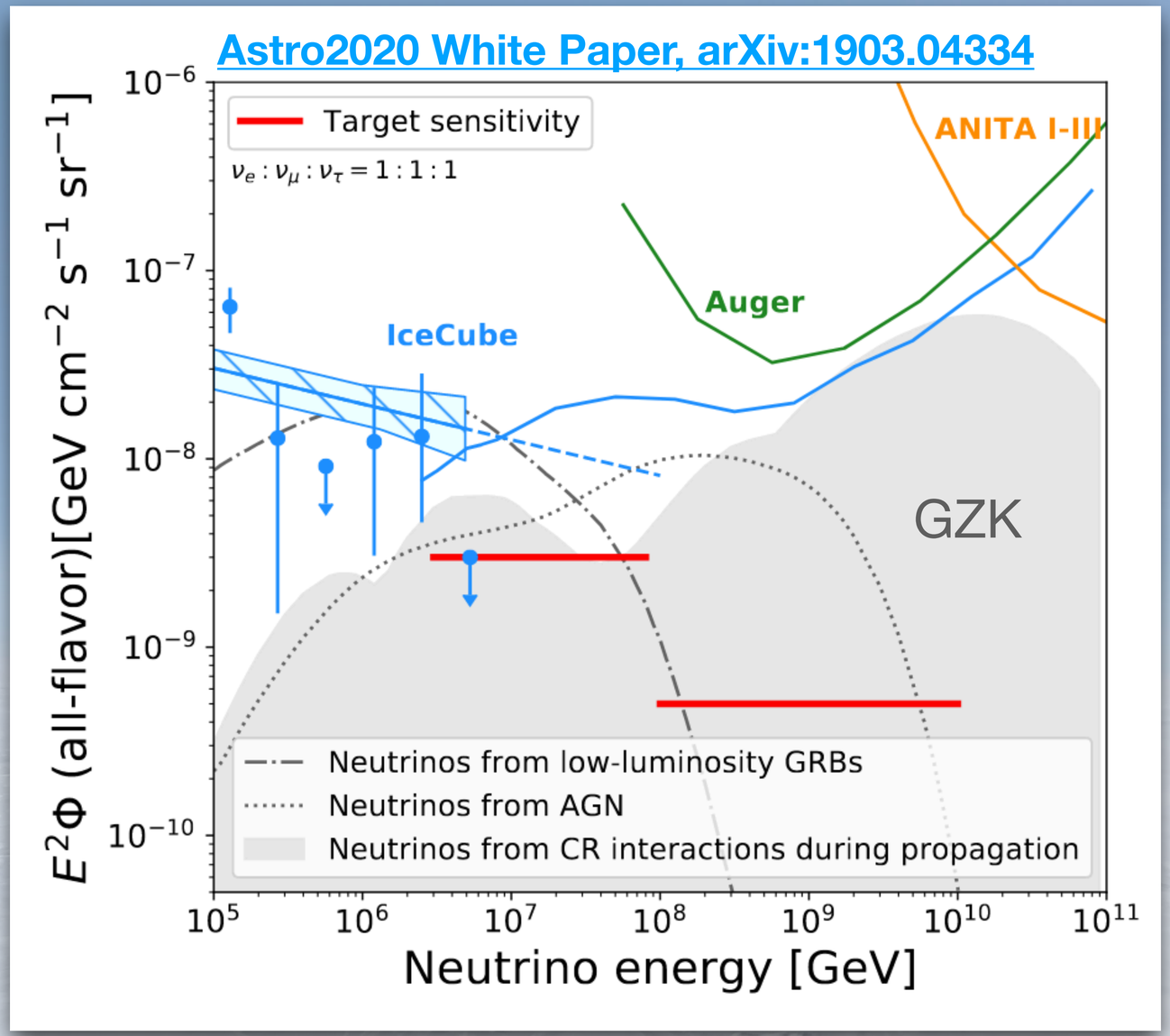
Ultra-high-energy neutrinos

Not yet discovered!

- No measurements above 10 PeV
- Open questions:
  - Cutoff in astrophysical spectrum
  - Existence of 2. astrophysical component
  - Existence of cosmogenic GZK neutrino flux

➡ Requires IceCube x 10 - 100

➡ In-ice radio detectors target energy range: 100 PeV - 10 EeV



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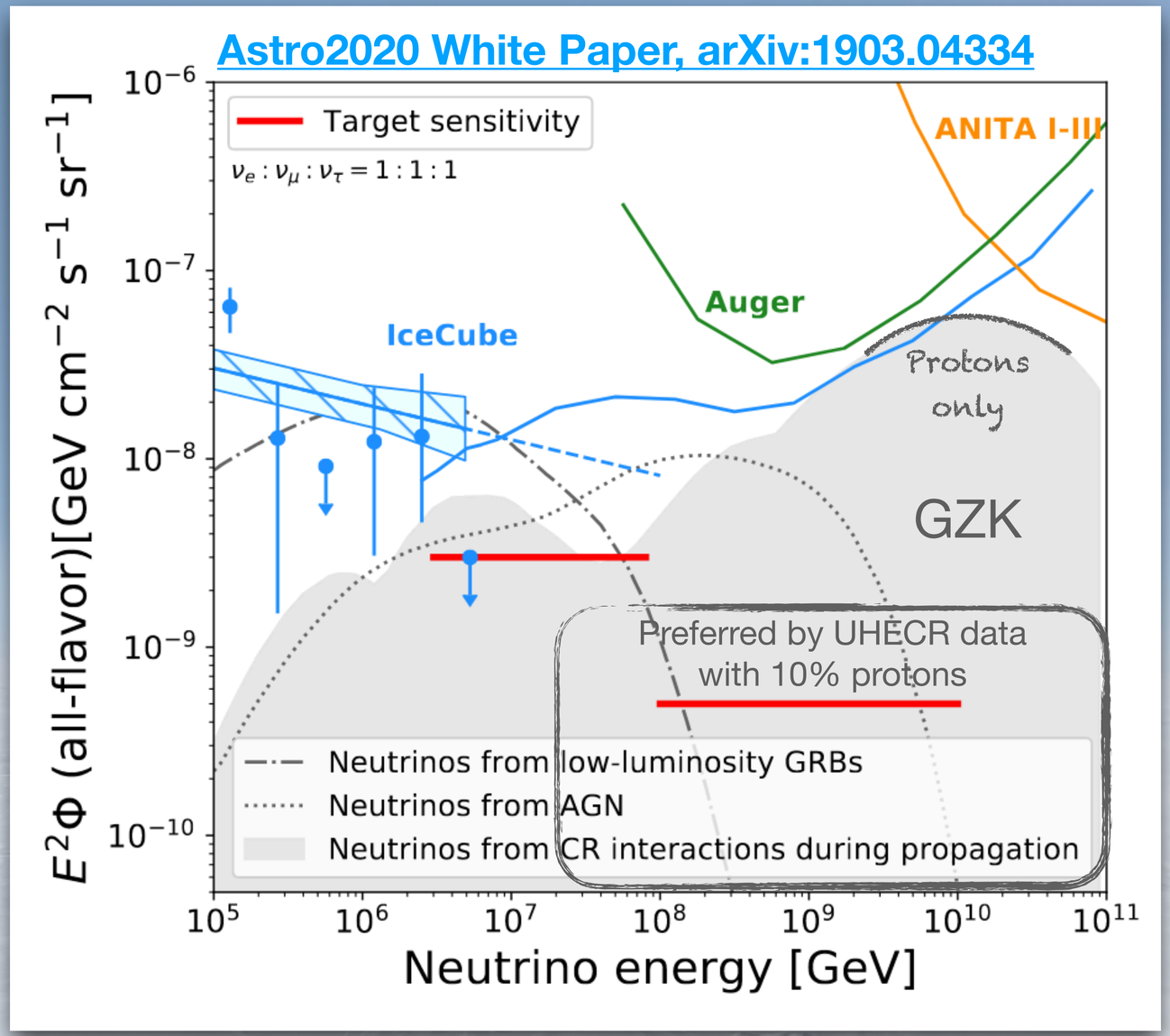
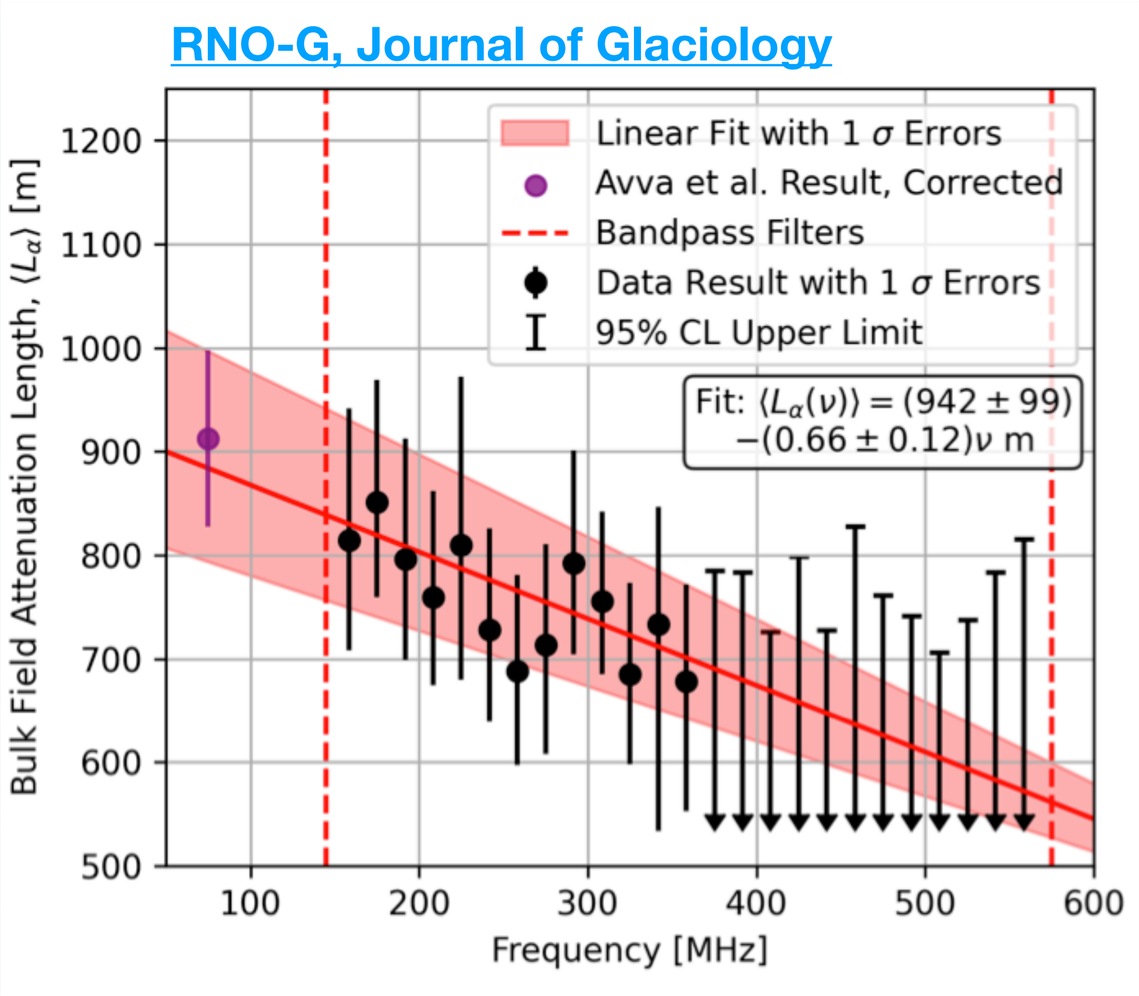


Radio detection of neutrinos

Why?

- Use natural glacier ice as target
- Radio waves are less attenuated in ice
  - A single radio station can monitor a cubic kilometer of ice
- Radio is a cost effective solution
  - In hardware & deployment (do not have to be deployed in 3 km depth; 100 - 200 m is sufficient)



Radio detection of neutrinos

How?

Buried in-ice antennas

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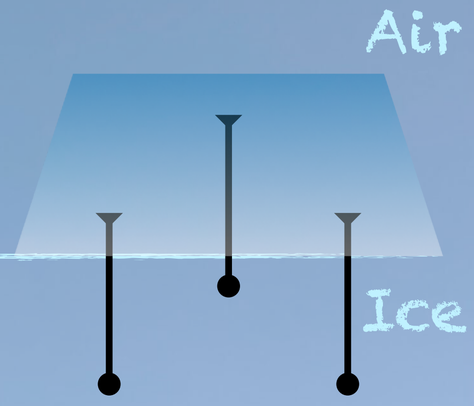
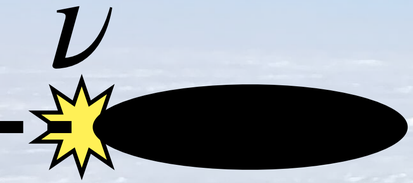


Particle cascade

E_{min} to detect radio emission $\gtrsim$ 1 PeV



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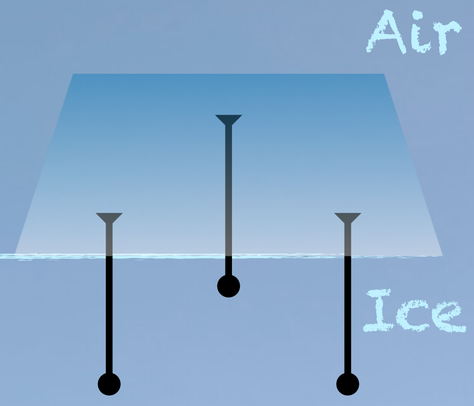

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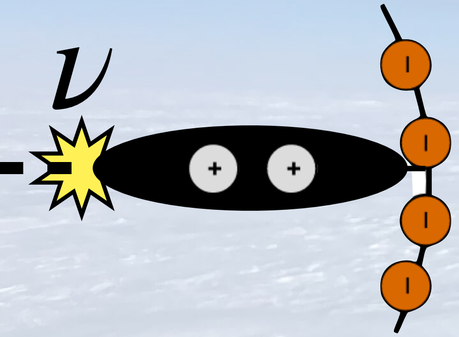

A negative charge-excess builds up (electrons are knocked out of ice) …

… and produces radio emission (Askaryan 1968)

Radio detection of neutrinos

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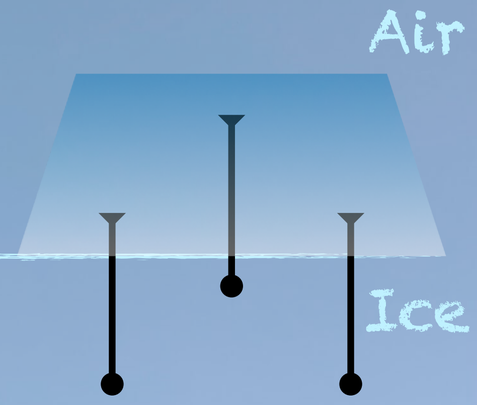

Buried in-ice antennas

Radio emission pattern has cone shape due to interference

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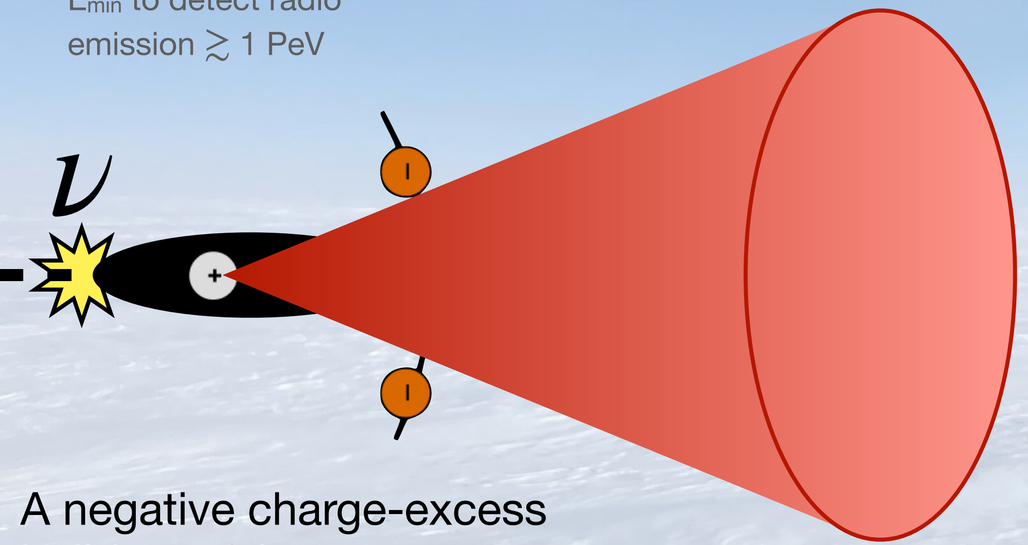

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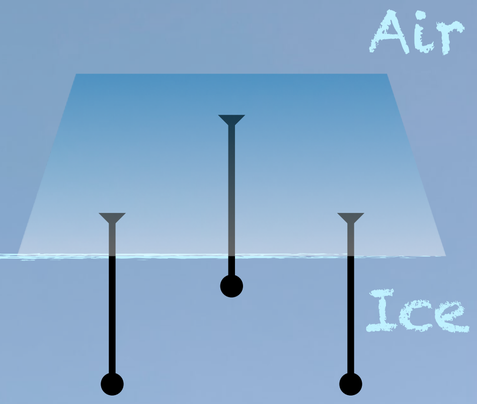

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Propagation through ice: Bend trajectory due to refractive index of ice

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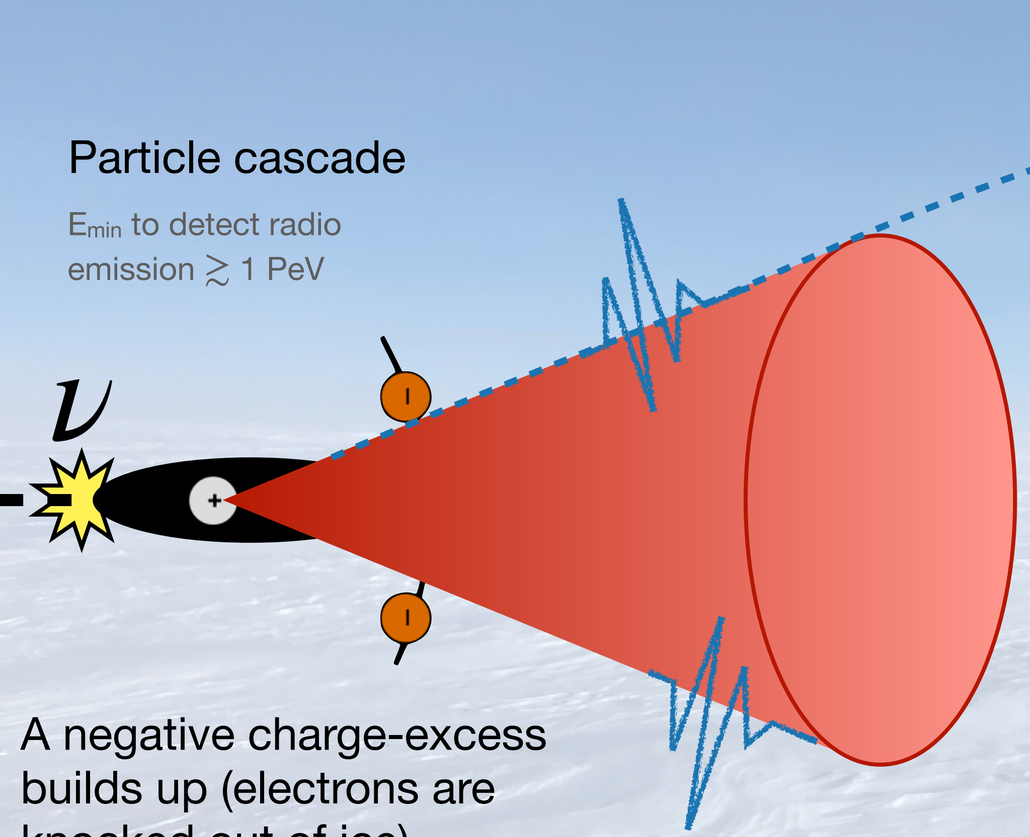

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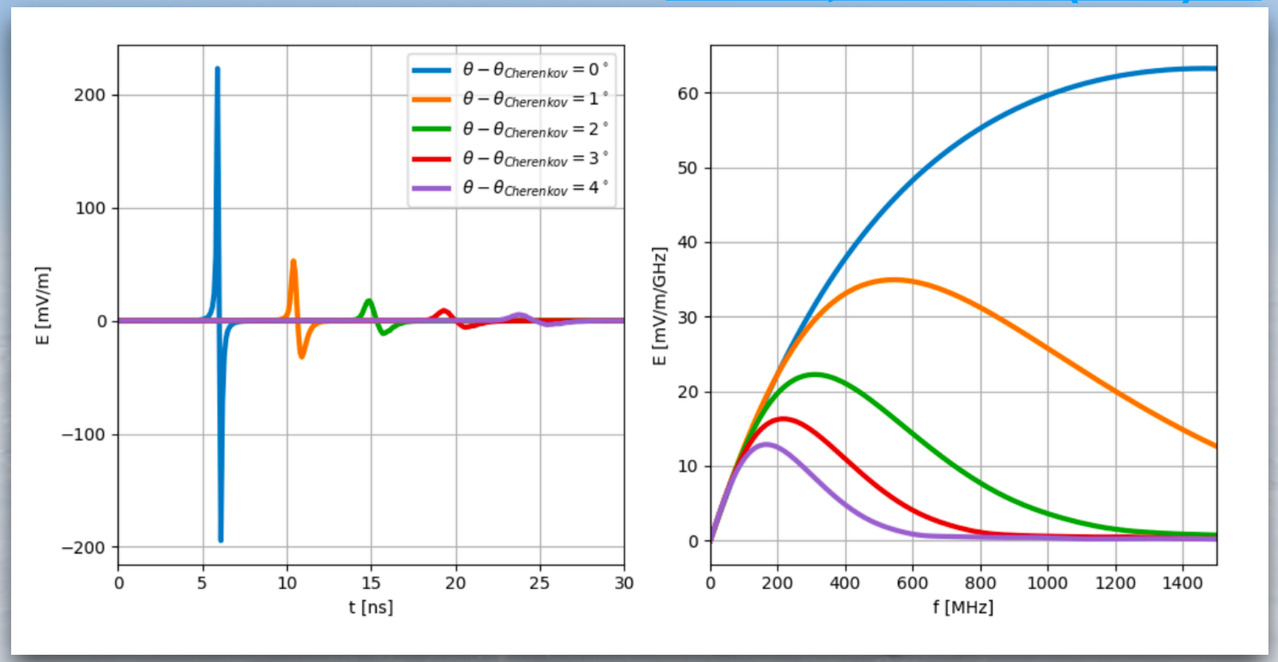
RNO-G, JINST 16 (2021) 03



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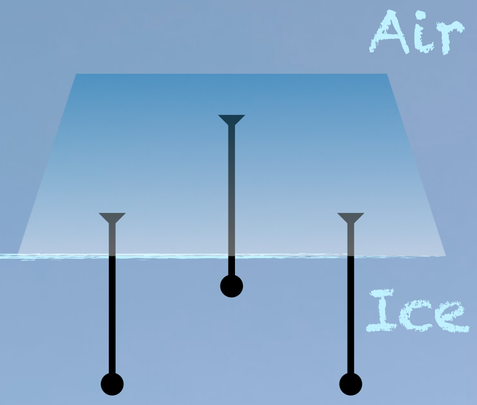

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Moving of cone reduces signal strength …

Propagation through ice: Bend trajectory due to refractive index of ice

… and higher frequencies vanish

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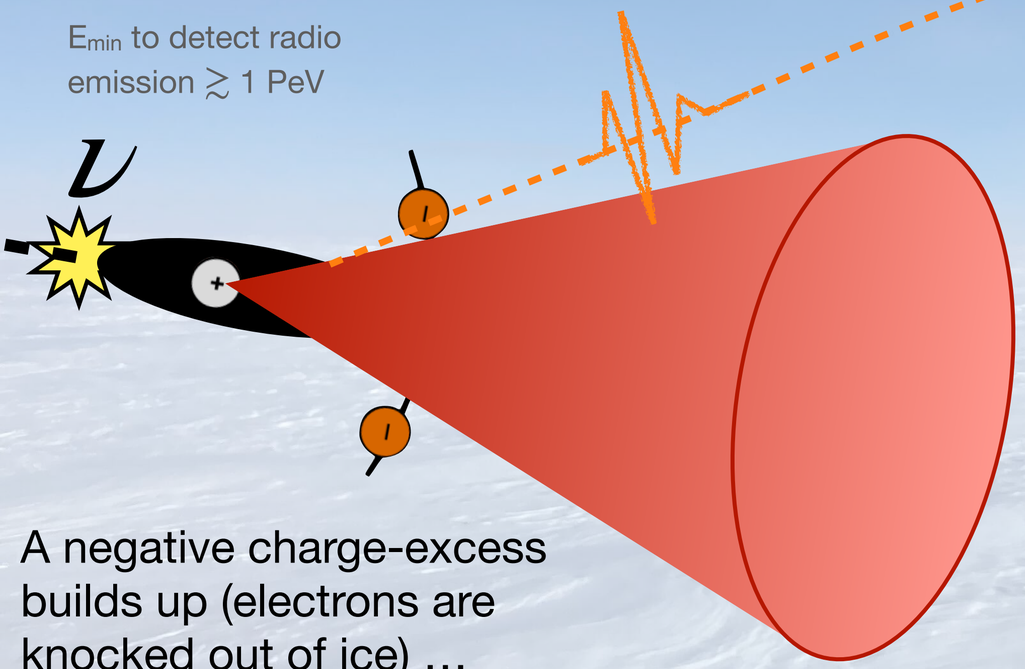

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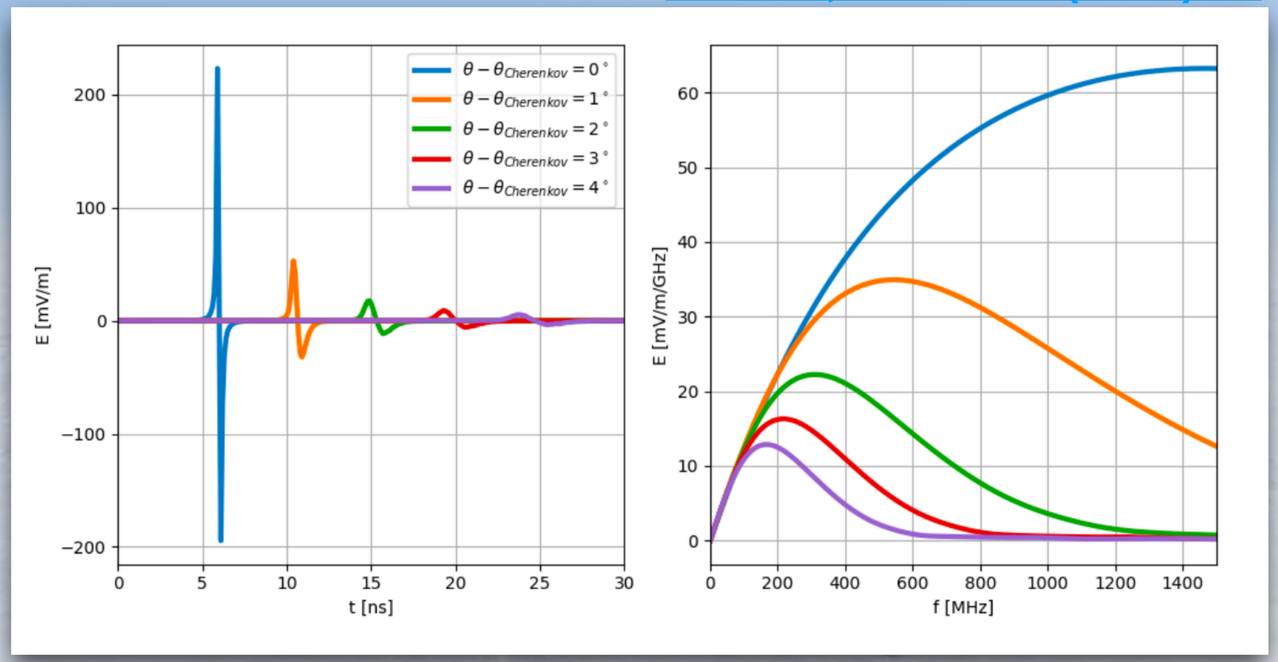

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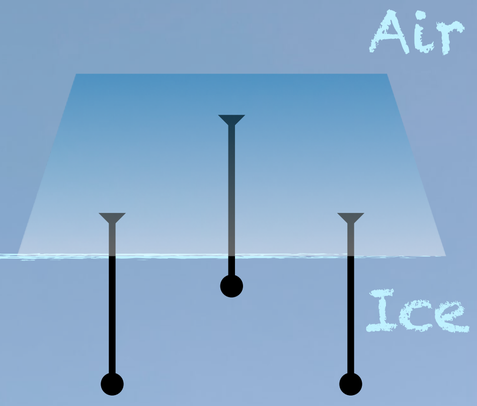

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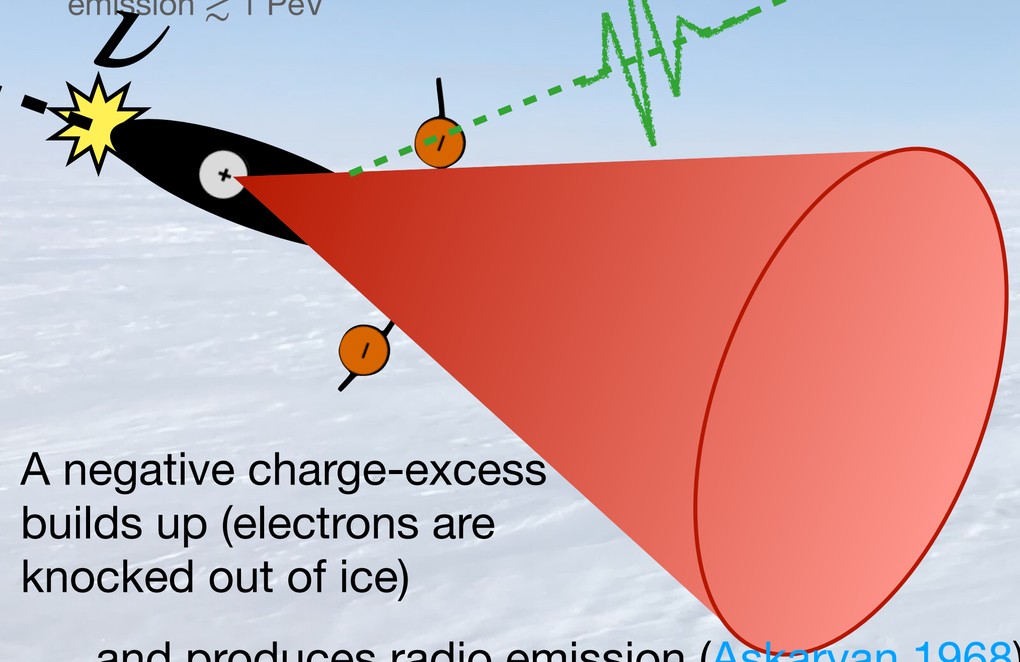

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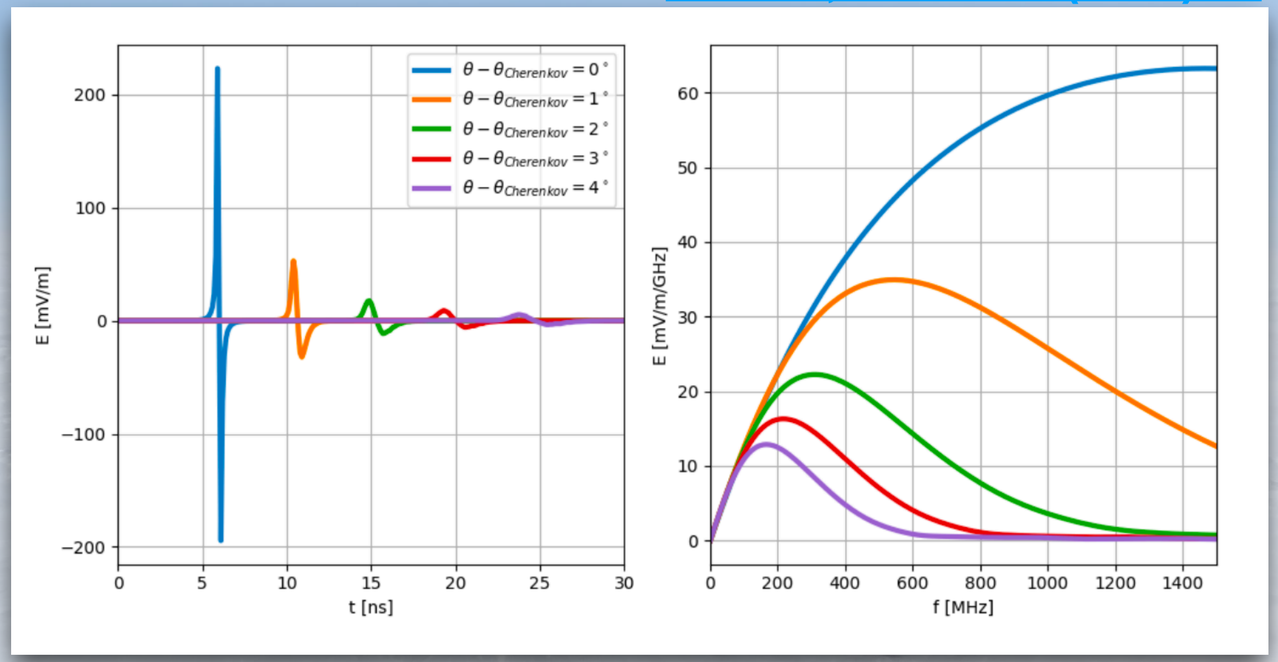
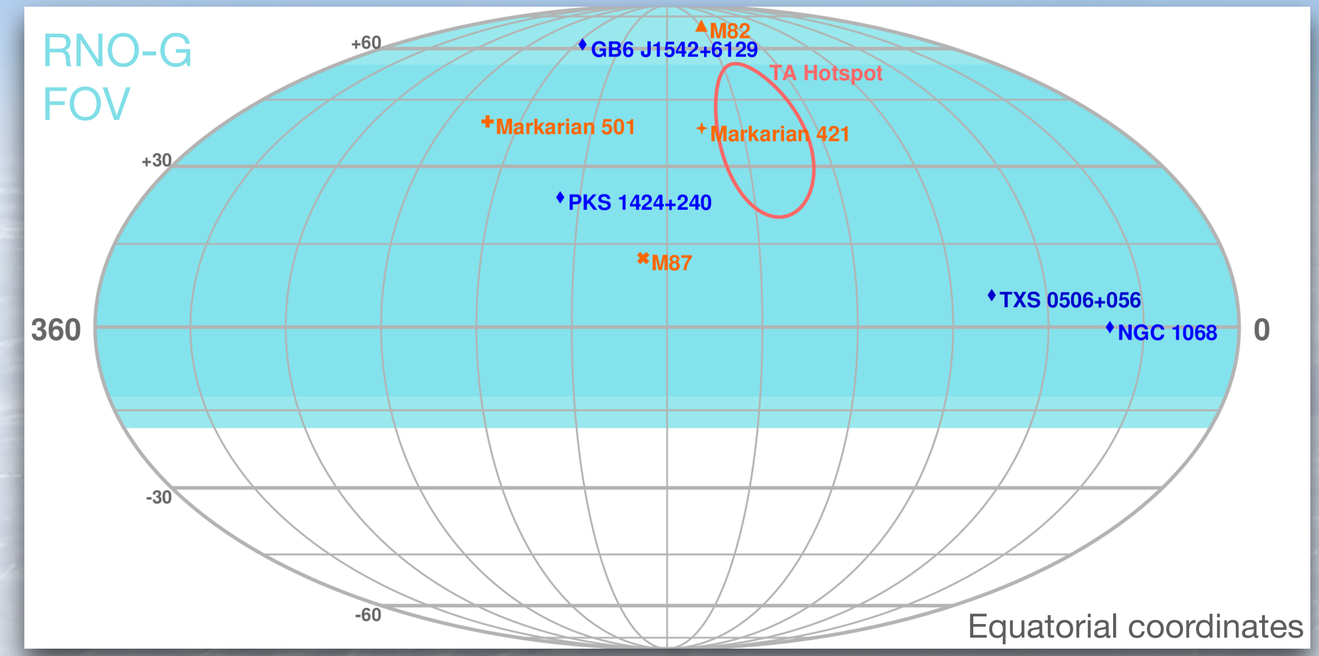


Radio detection of neutrinos

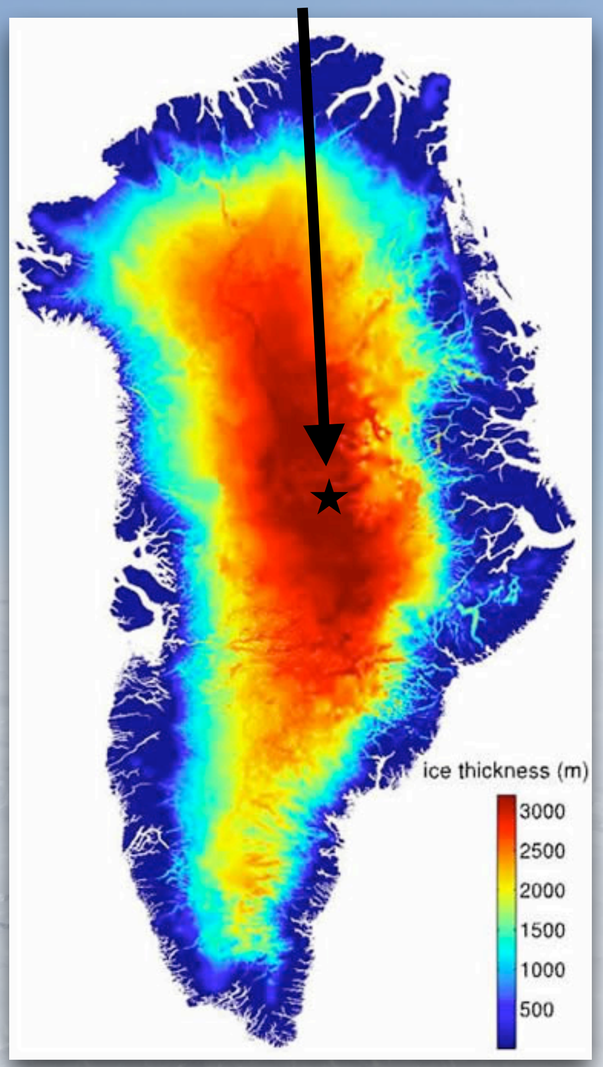
Where?

- Existing infrastructure, 10 months of sunlight per year
- Same sky observable as IceCube for TeV neutrinos
- Complementary field of view (FOV) with future UHE observatory at South Pole



Greenland!

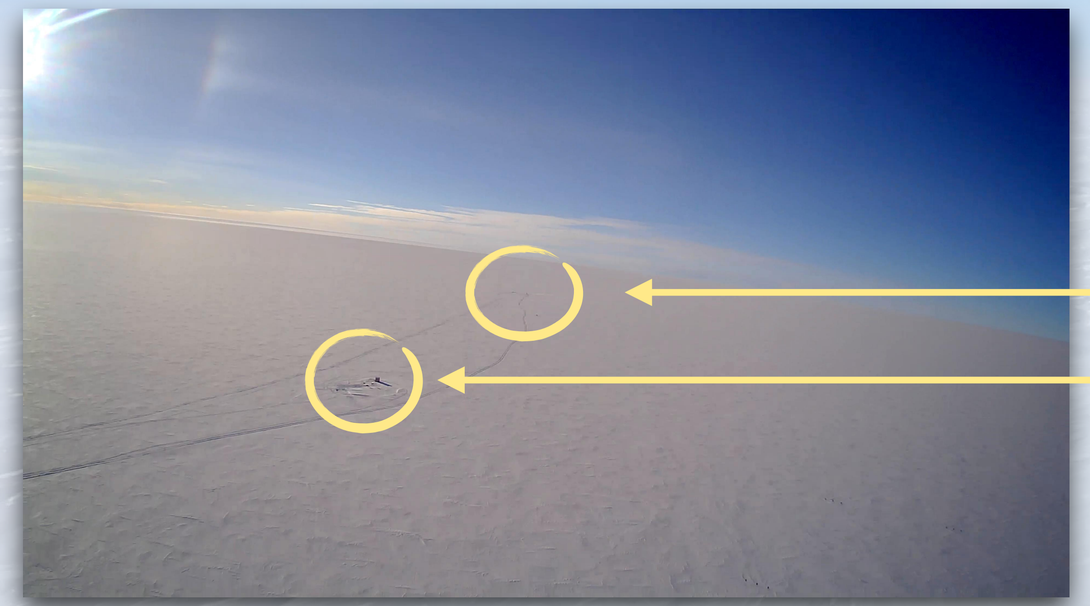
@ Summit station

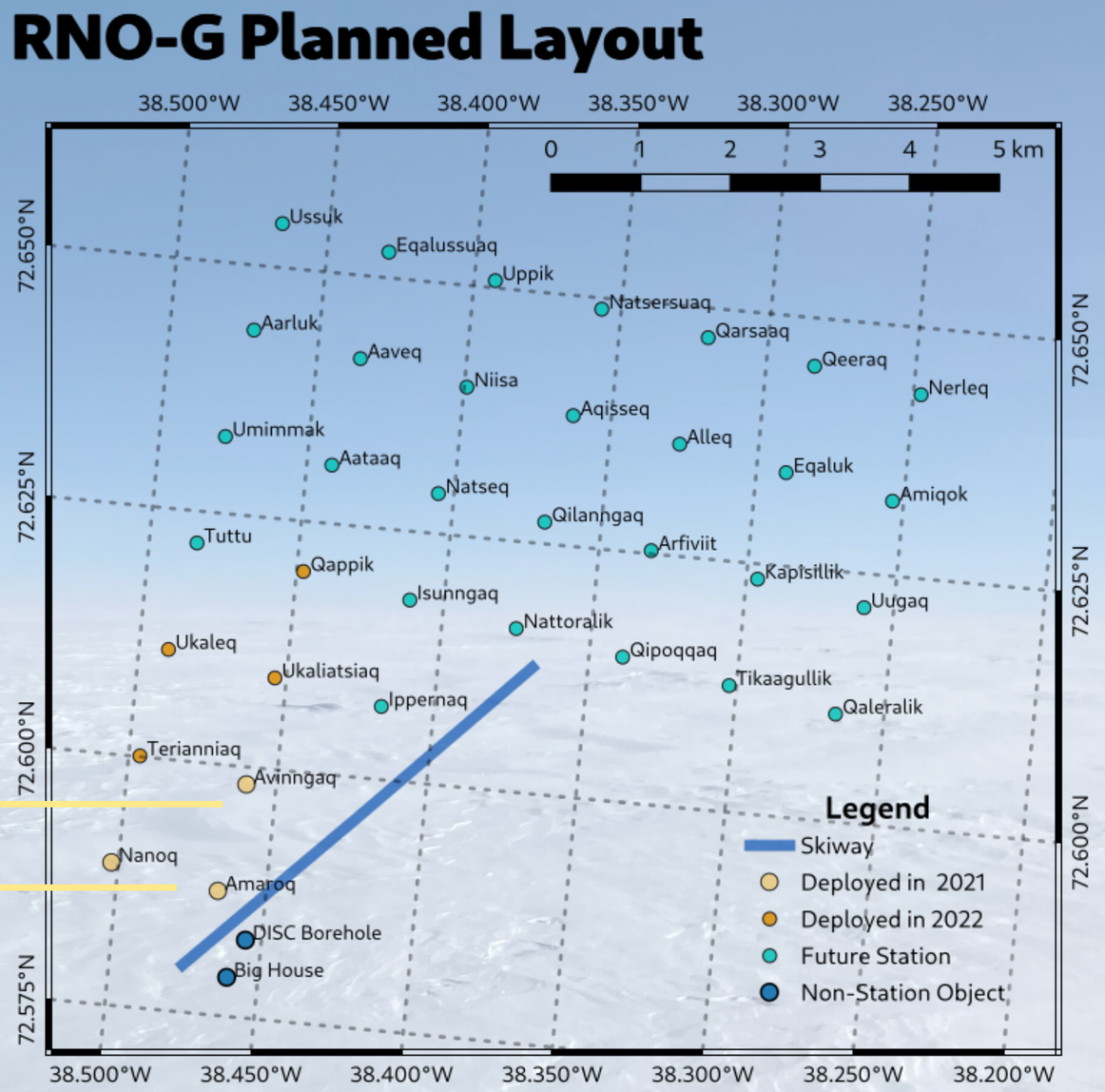


Radio Neutrino Observatory - Greenland

The UHE Neutrino Observatory in the Northern Hemisphere

- 35 stations on 1.25km grid
  - 7 already deployed & taking data
  - 3 - 4 more deployment seasons
- At Summit Station
- Stations are solar powered & communicate wireless

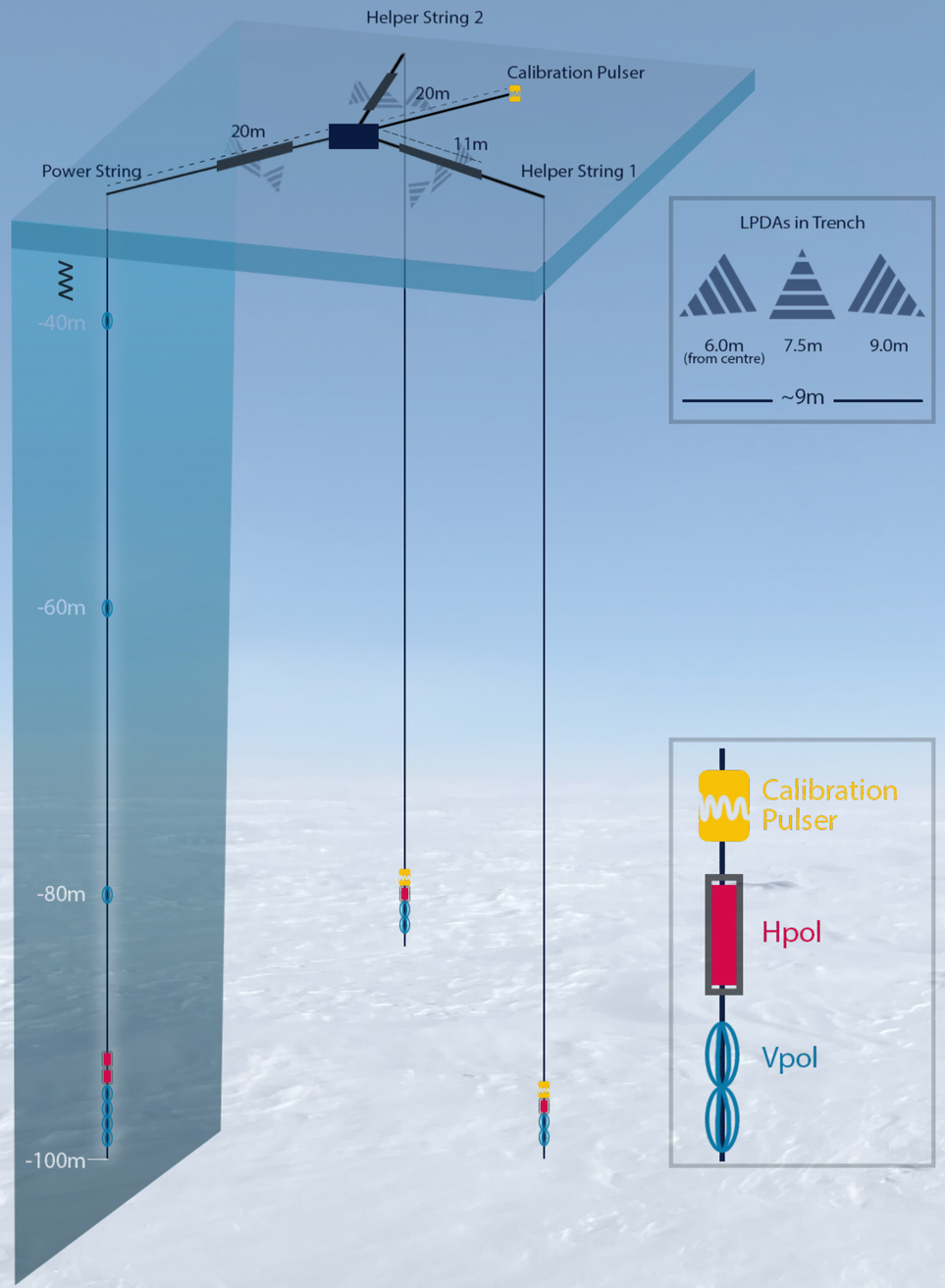




Station design

A hybrid concept

- 24 antennas
  - 3 types
  - ~ 80 - 650 MHz
- 3 calibration pulsar
- Informed by pilot experiments (ARA & ARIANNA)
- Will inform IceCube-Gen2 radio array design



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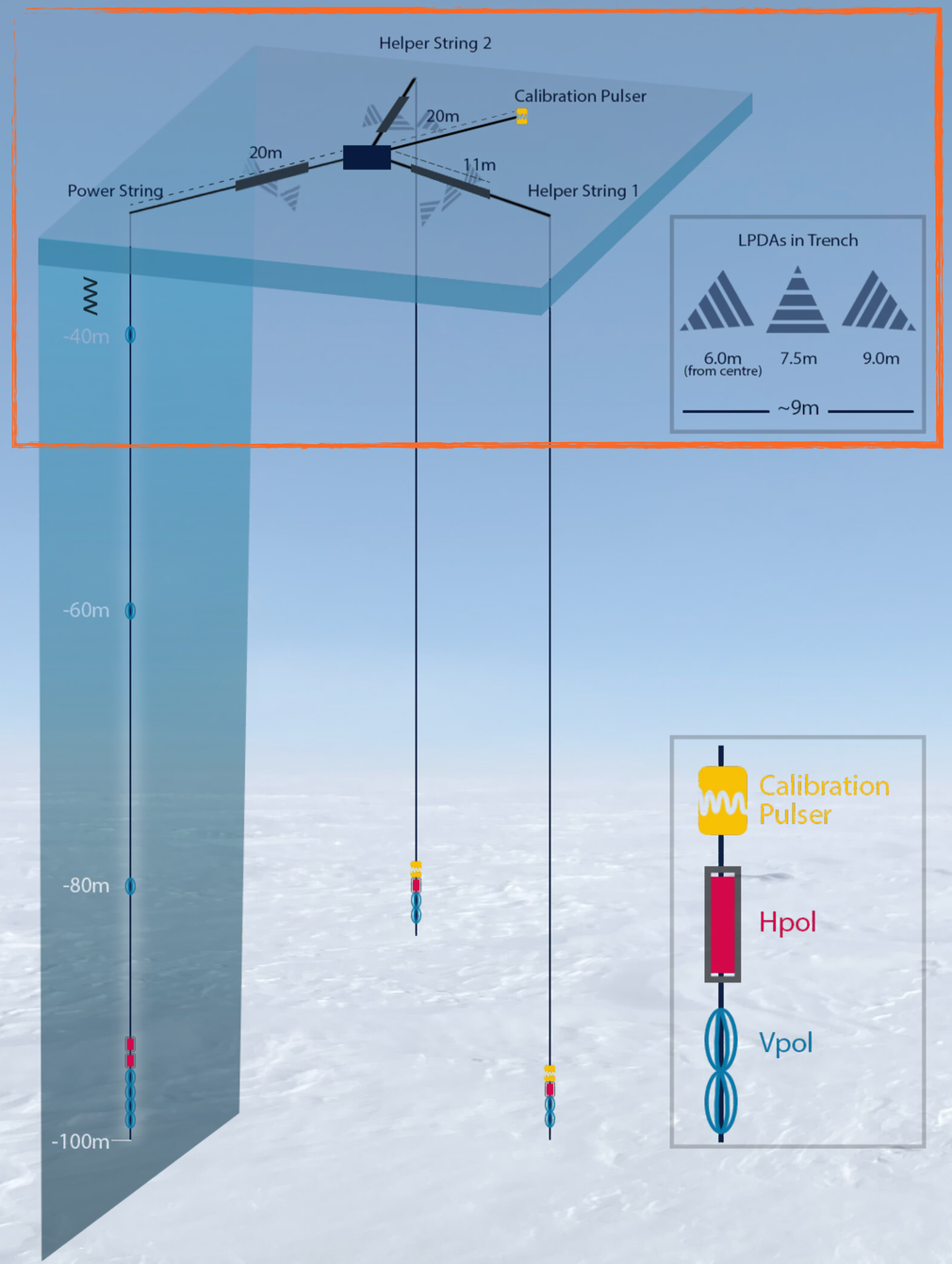

Shallow component

- Upward- & downward-facing LPDA antennas
- CR detection + veto
- Accurate polarisation reconstruction
- Multiple coincidence threshold trigger

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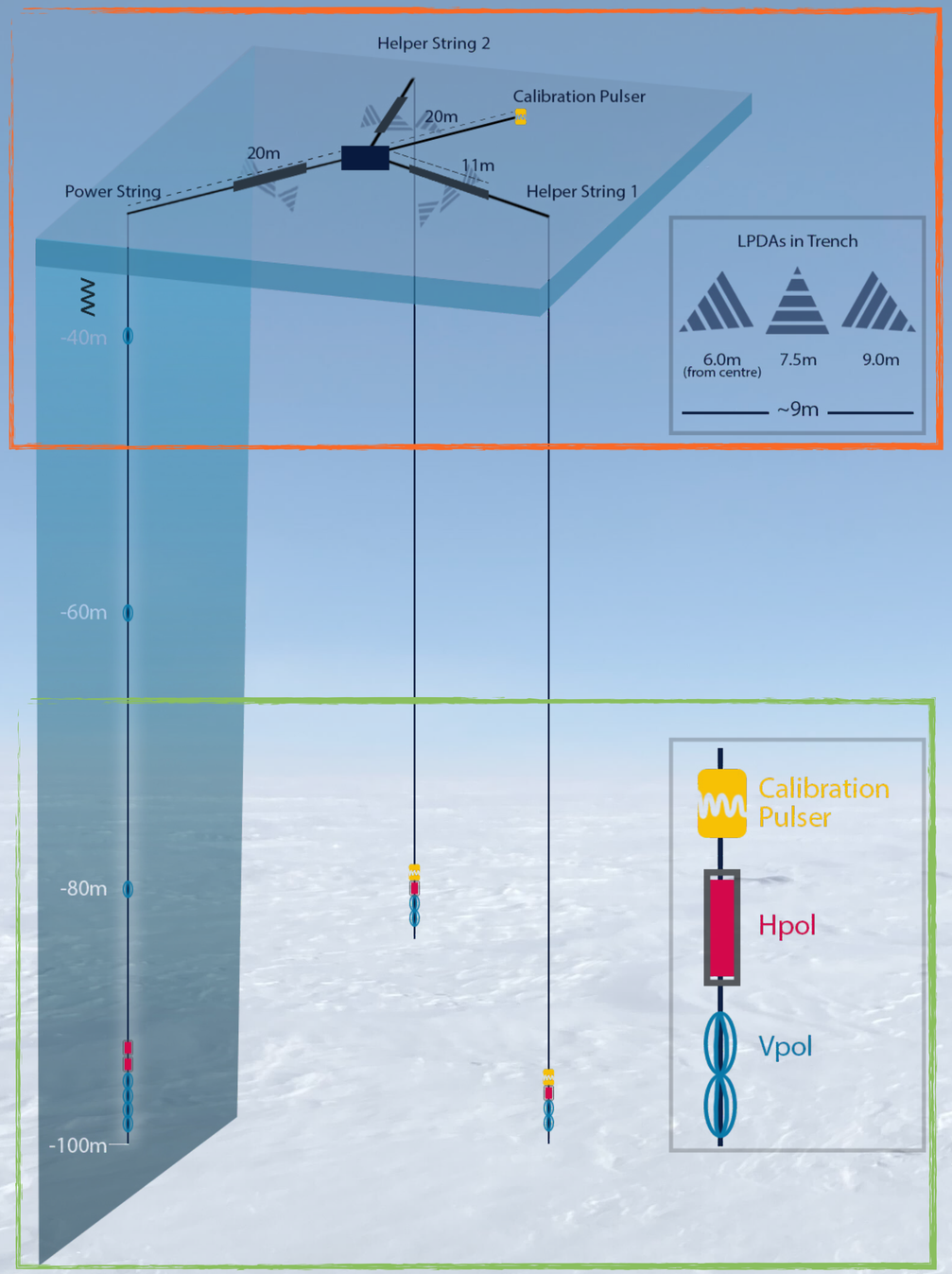

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Deep component

- 100m deep
- “Overlook” larger volume
- Low threshold trigger

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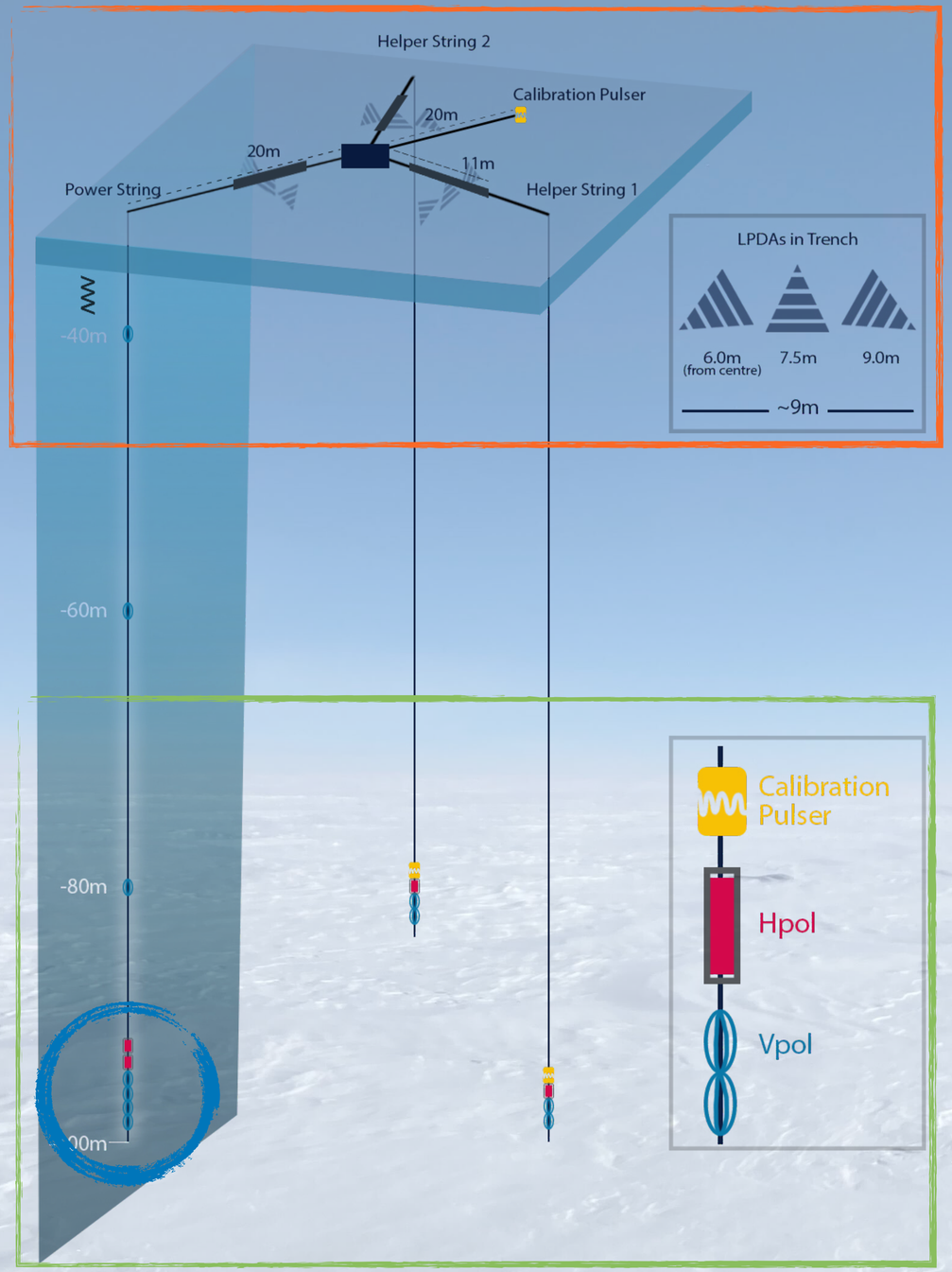
Phased array

- Signal of 4 Vpols combined by phasing into 8 beams in real time



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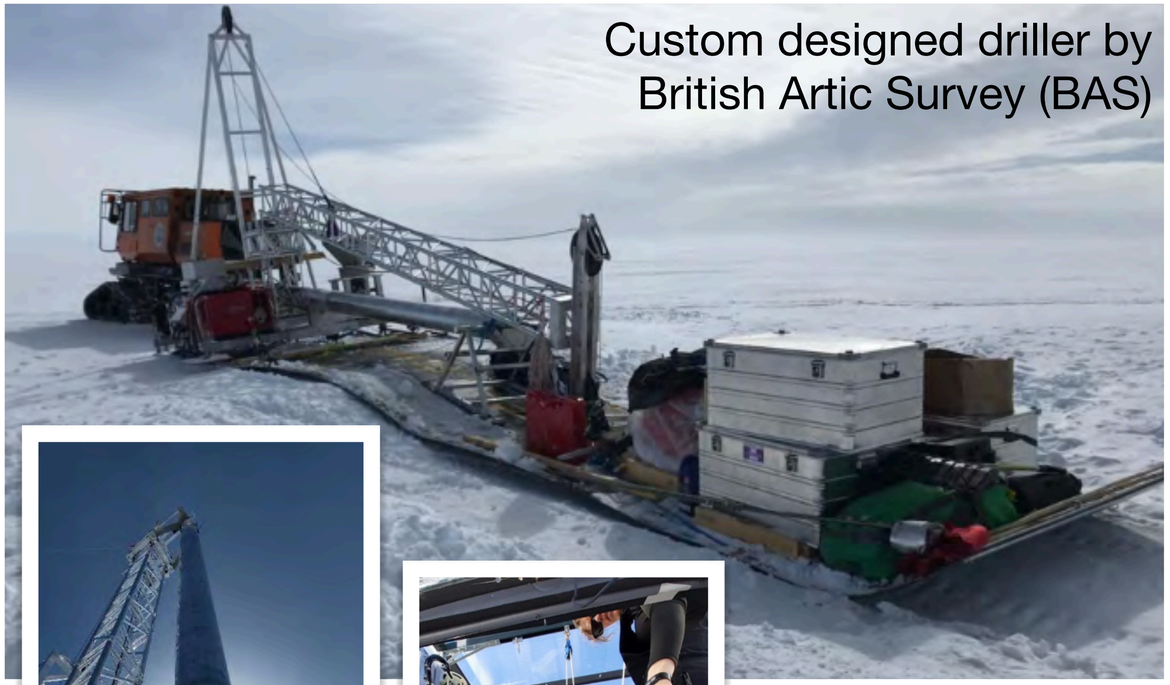
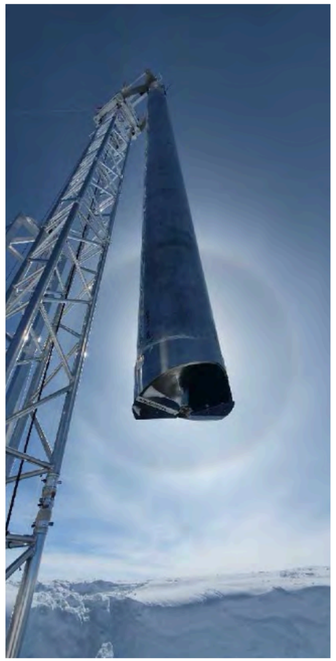
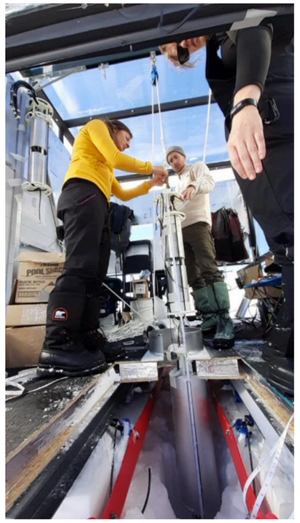
Deployment

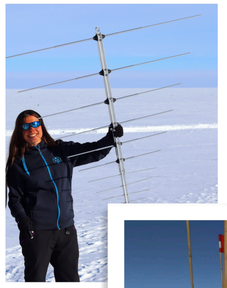
Drilling 100m deep, 28 cm diameter hole

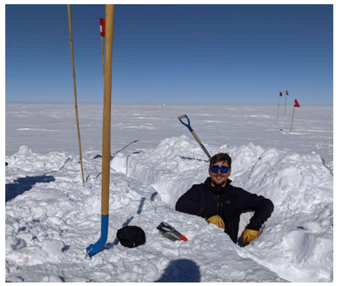






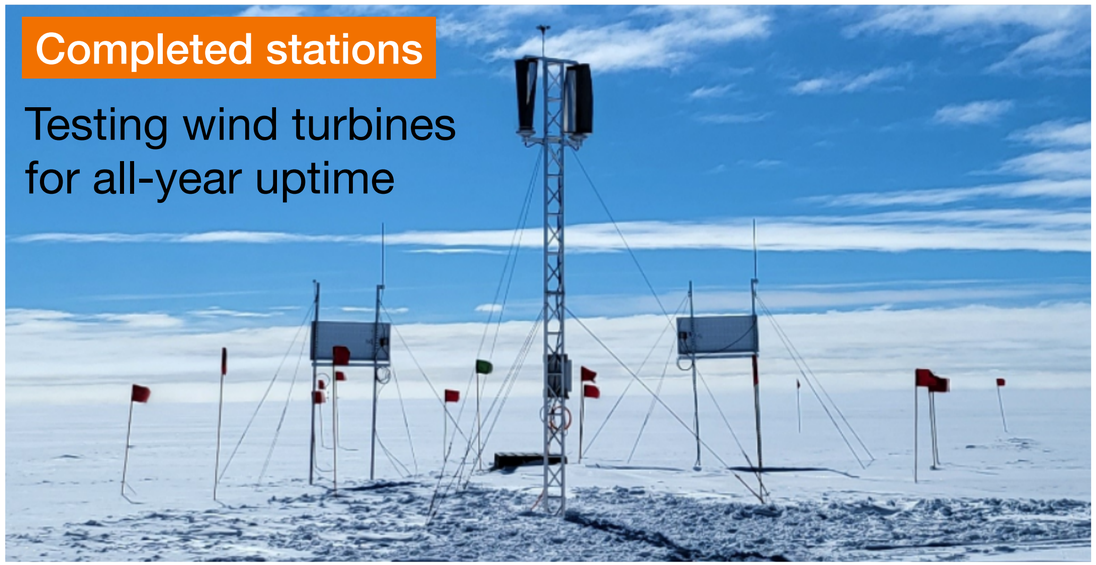
Shallow antennas are deployed in trenches …





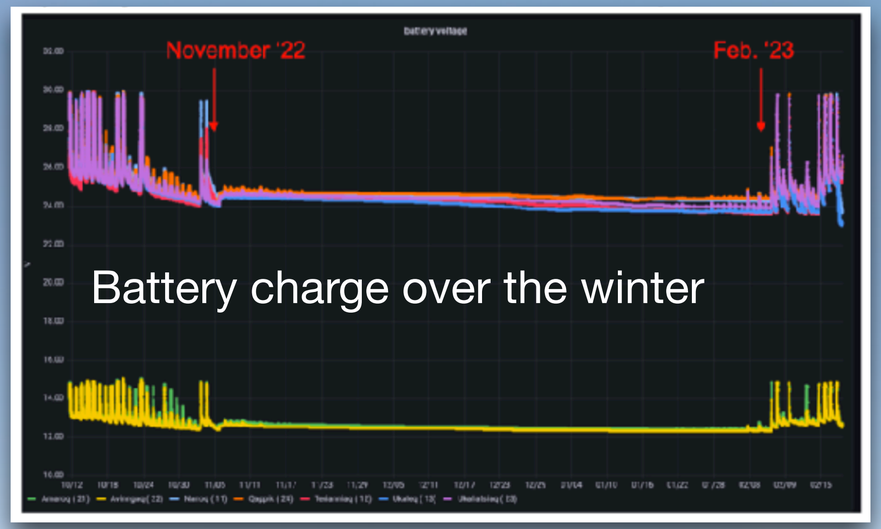
Completed stations

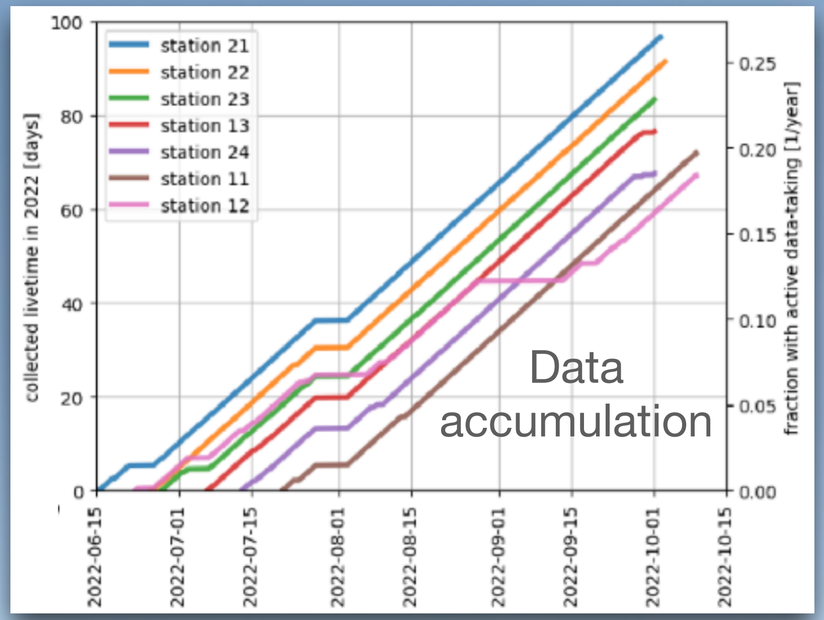
Testing wind turbines
for all-year uptime

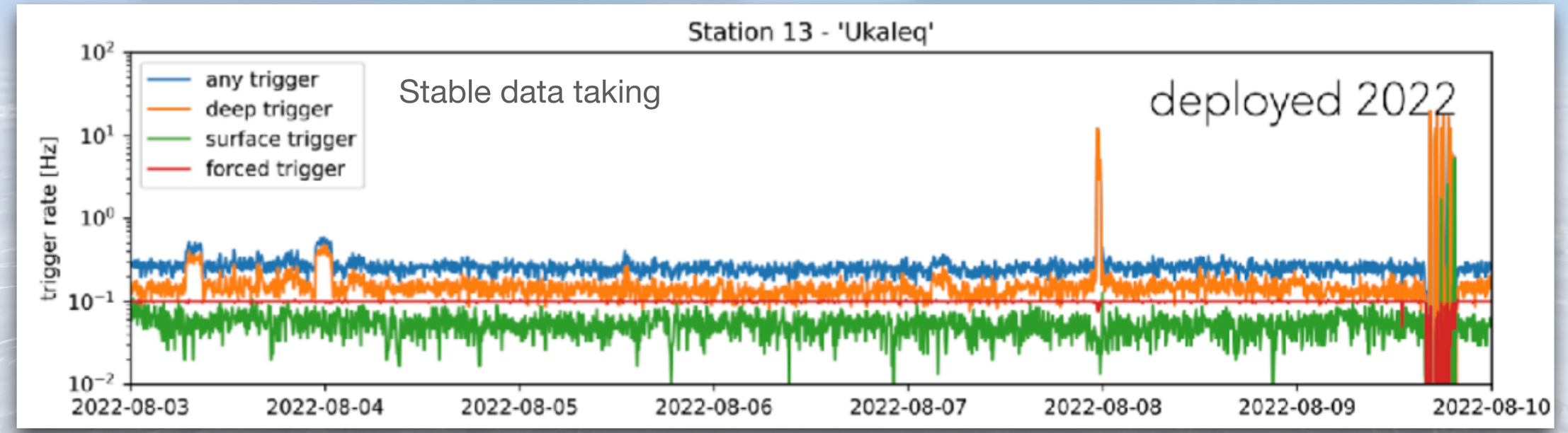


Hardware performance

Aka surviving the winter!



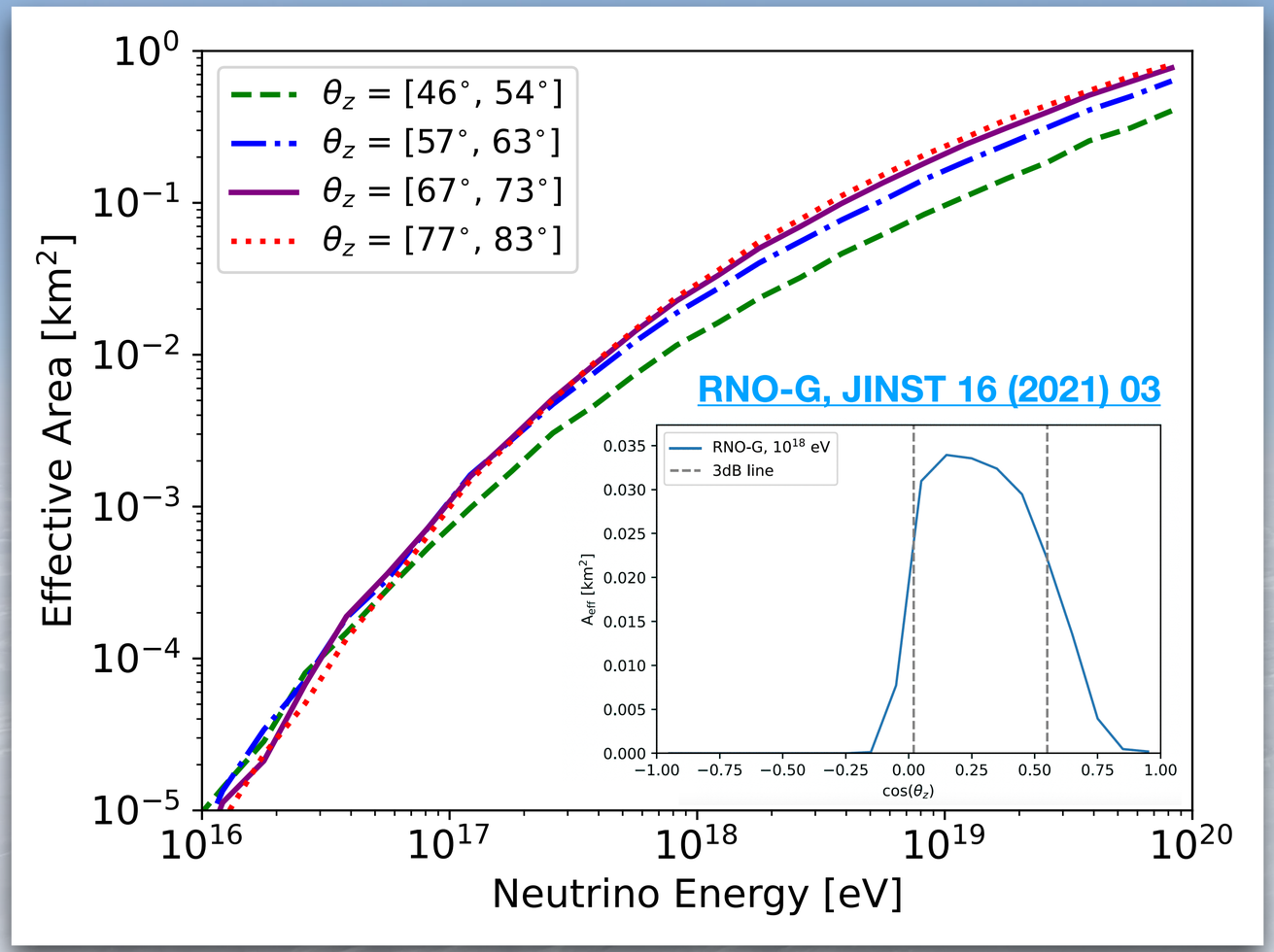


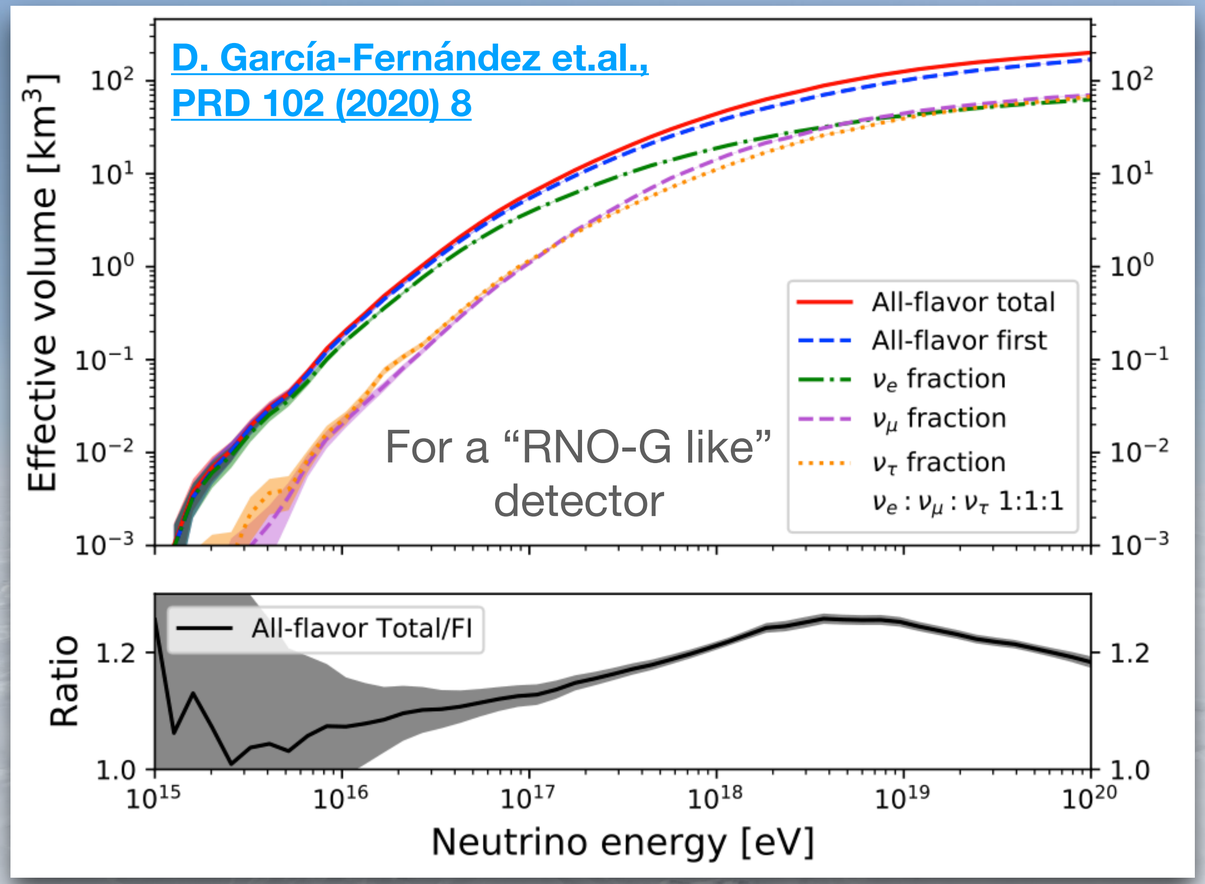


Detecting neutrinos with RNO-G

Effective area

- Largest aperture just above the horizon
- Sensitive to all flavours



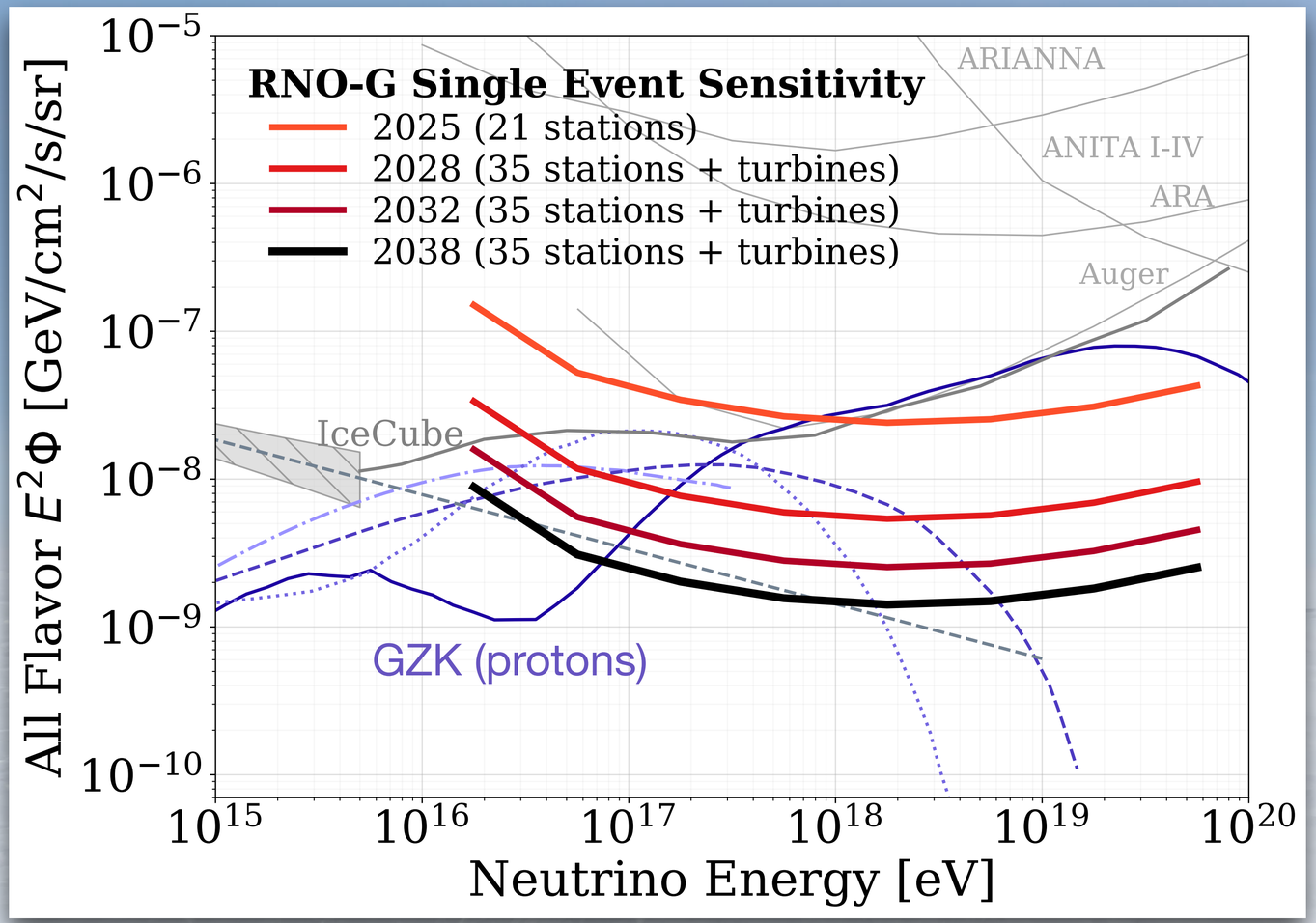


Notice different y-axes!

Sensitivity

to a diffuse emission

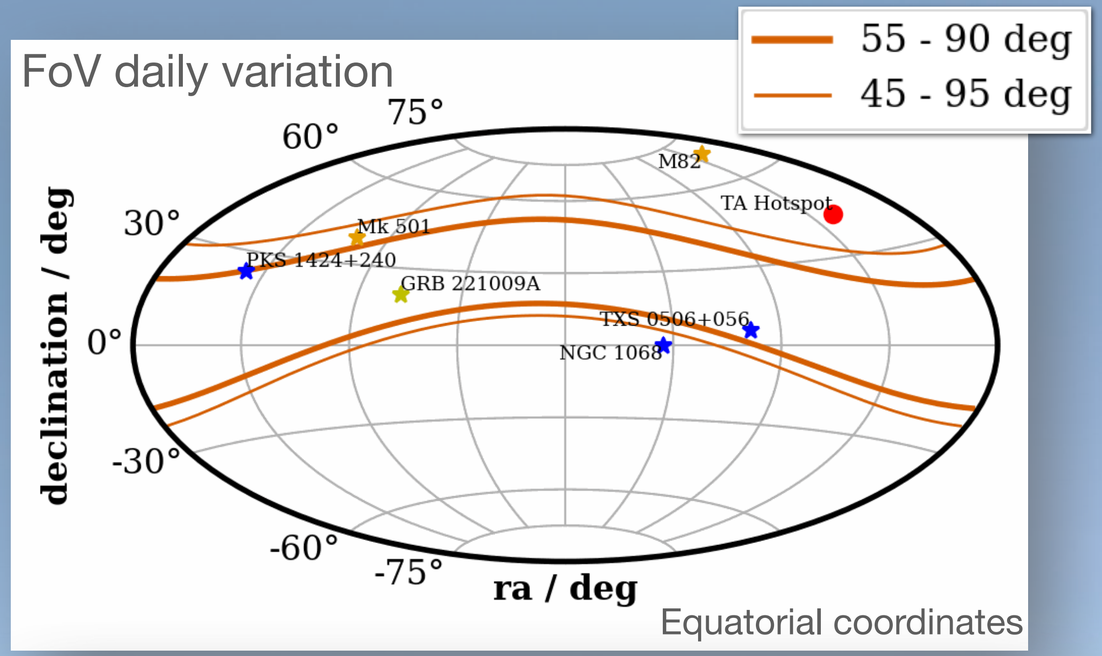
- World leading sensitivity @ 1 EeV
- Cosmogenic neutrinos from proton interactions with the CMB (GZK cutoff)
  - Not discovered yet
  - RNO-G will confirm or reject the most promising flux expectations
- Unresolved point source
  - Extension of astrophysical flux measured by IceCube
  - Potential to discover a hardening
- Expect low background

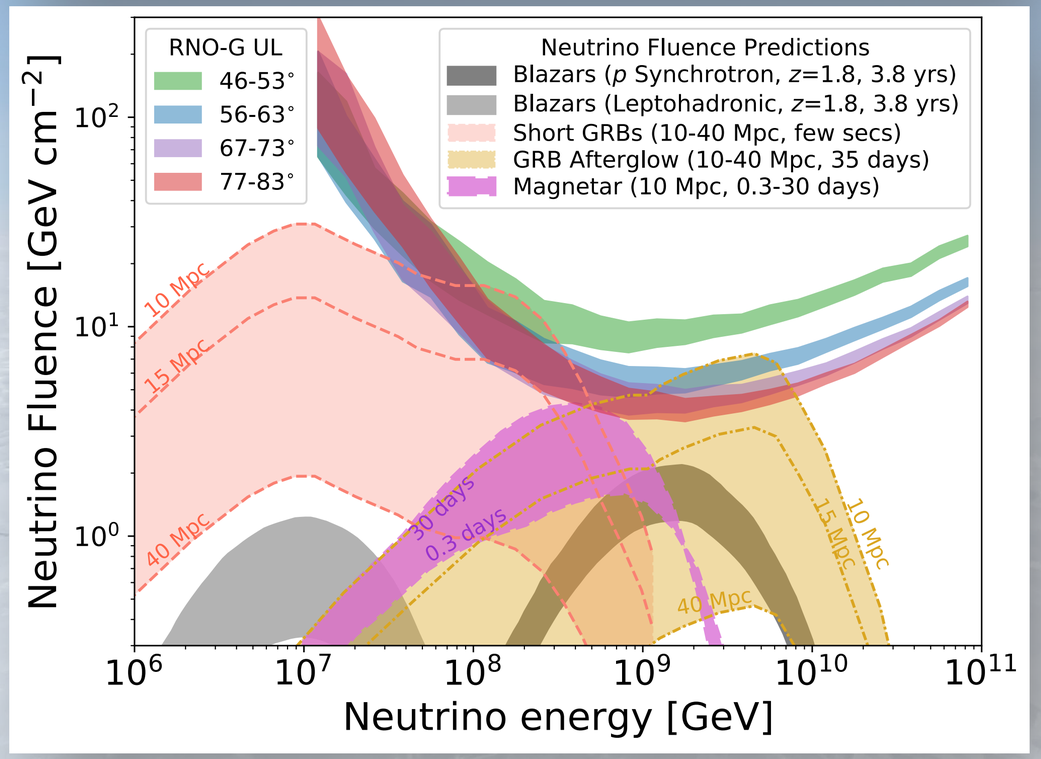


Sensitivity

to transient events

- Relevant for multi-messenger observation!
- Able to observe nearby GRBs
- Largest (only) UHE neutrino observatory in northern hemisphere
- Contributor for multi-messenger search also after IceCube Gen2 Radio





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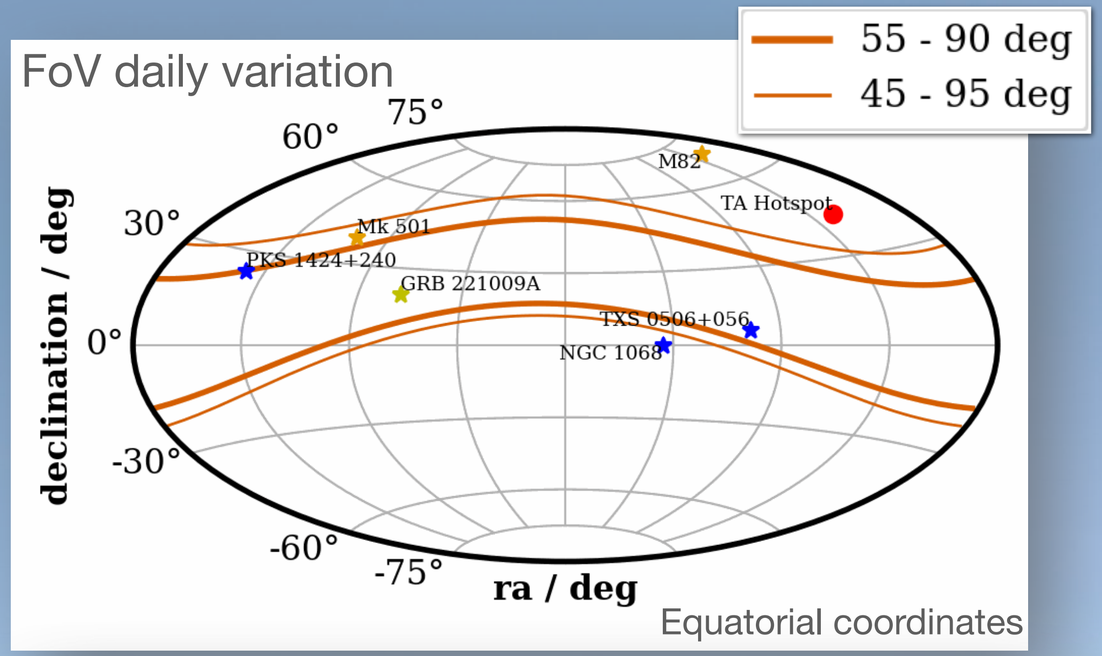
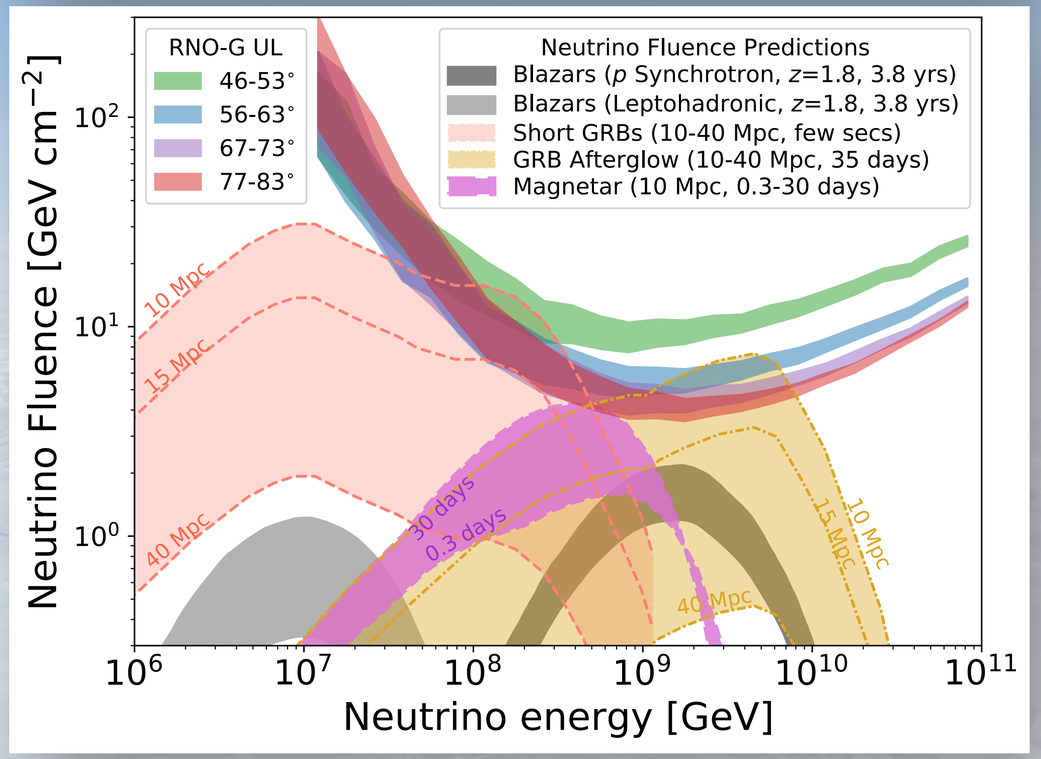
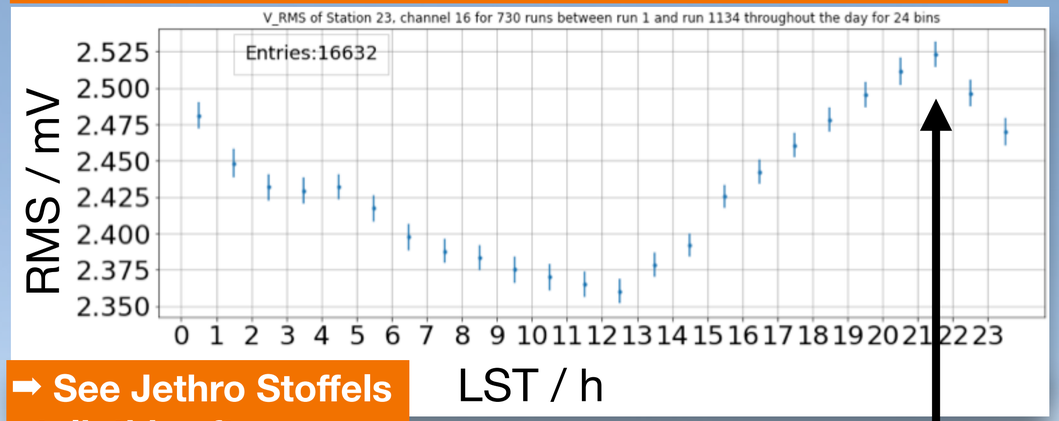




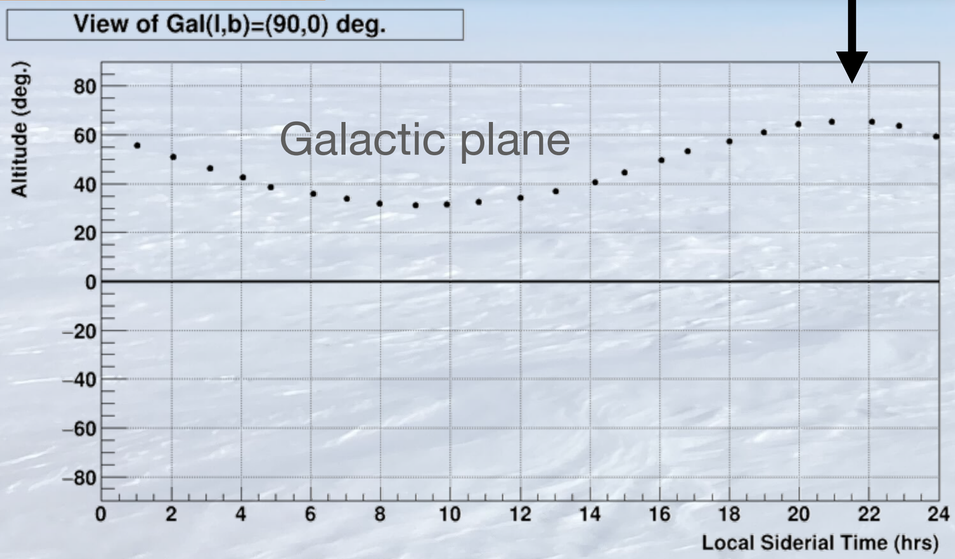
First look into the data

Verifying detector performace

Search galactic emission as daily modulation in received power in local sidereal time

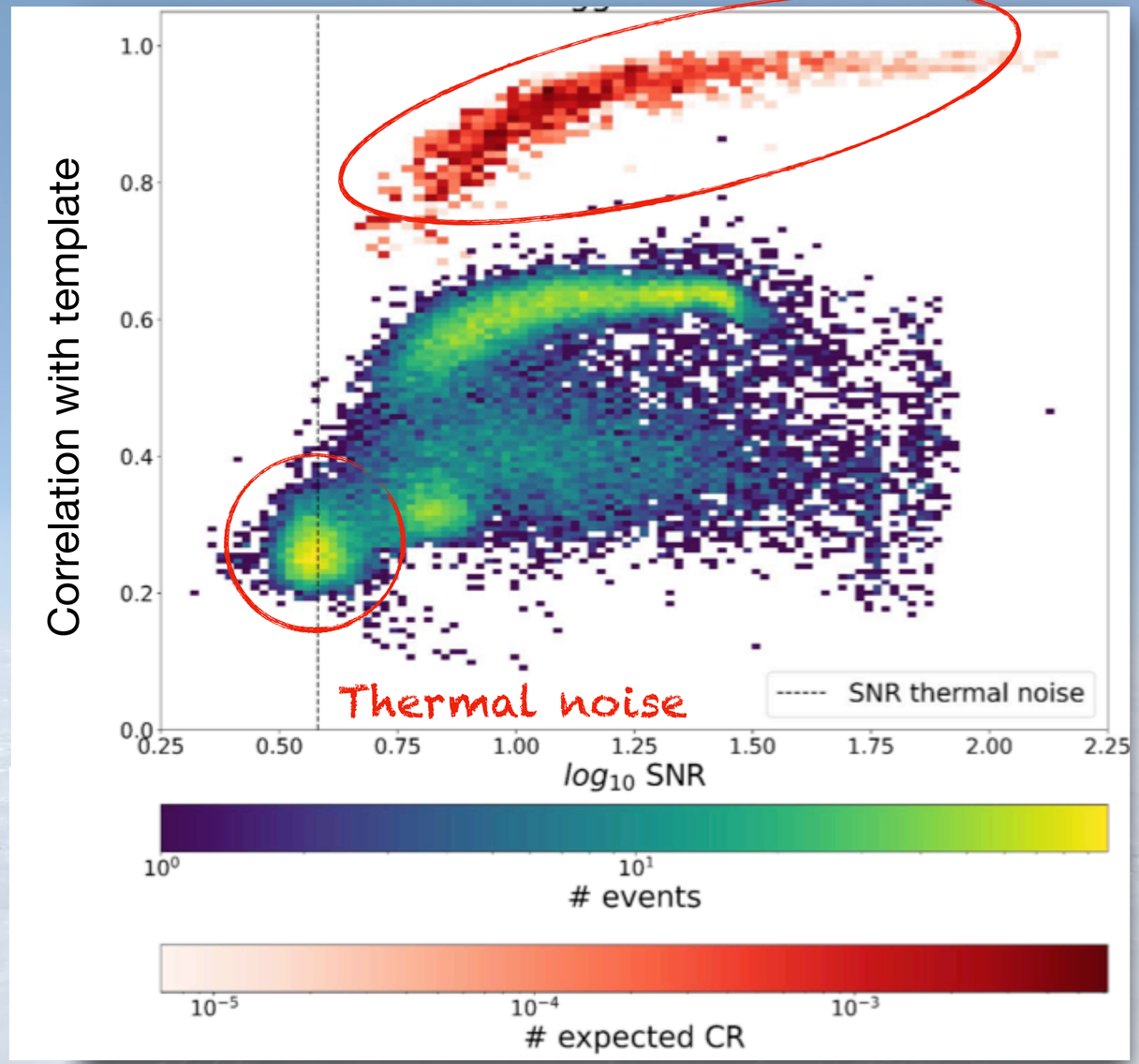


➡ See Jethro Stoffels talk this afternoon



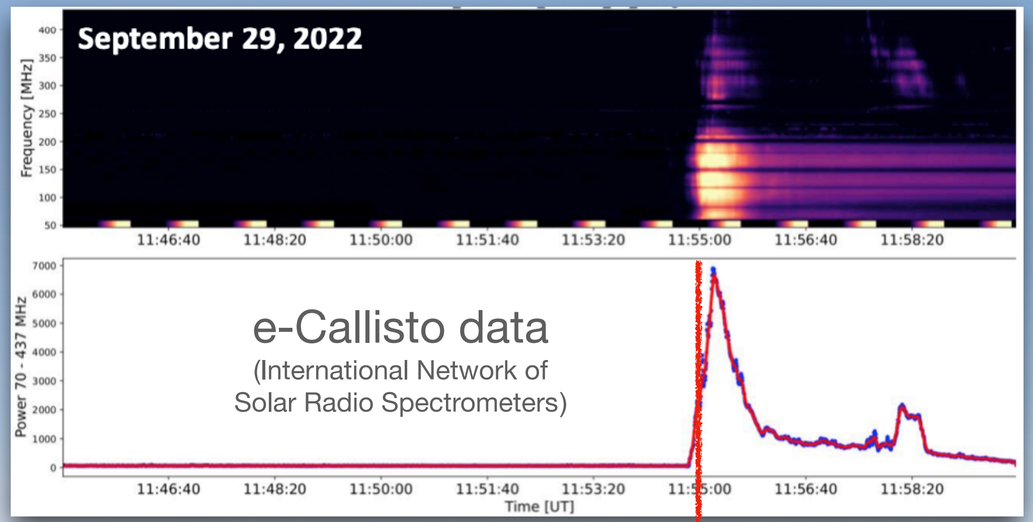
Cosmic ray search with signal templates

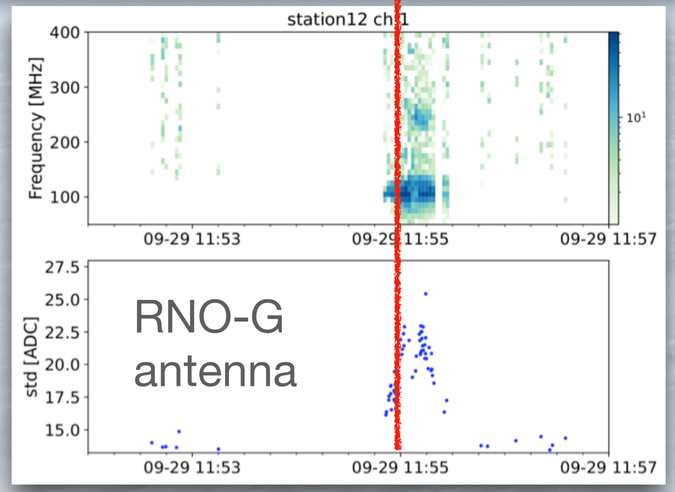
Simulated CR signals



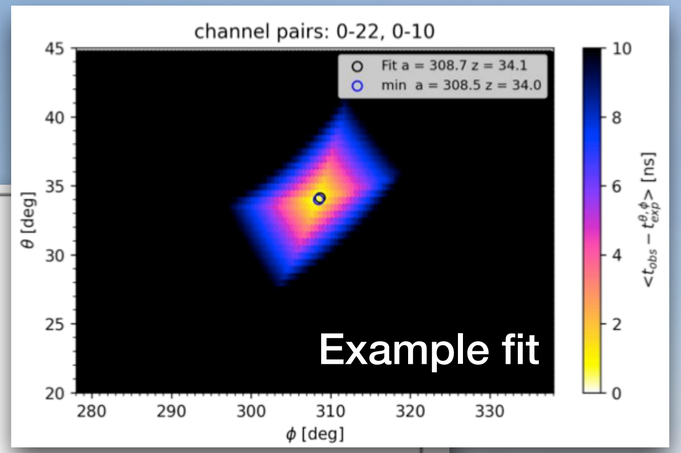
First look into the data

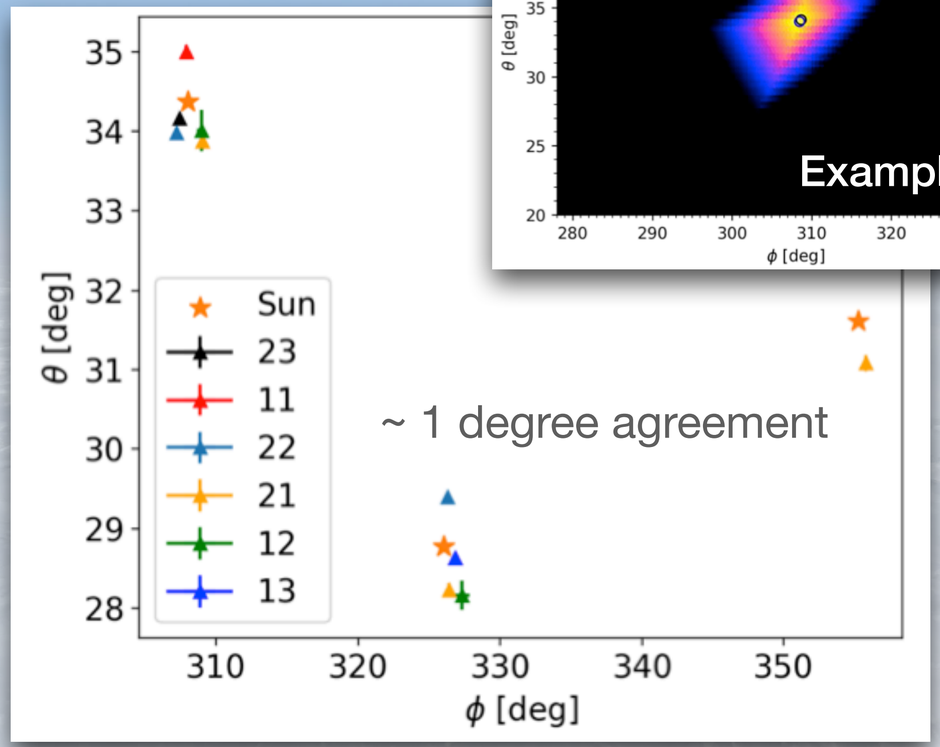
Correlation with solar flare





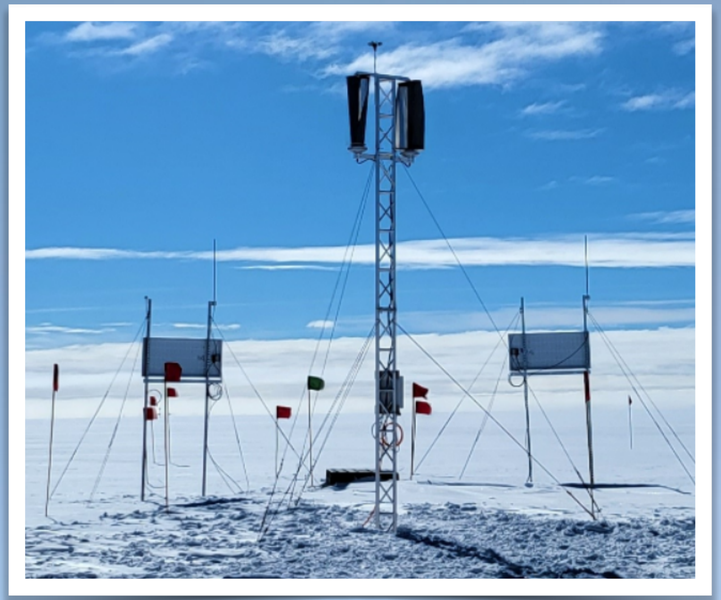
- For 3 solar flares, reconstruct position of Sun
- Allowed correction of station geometry

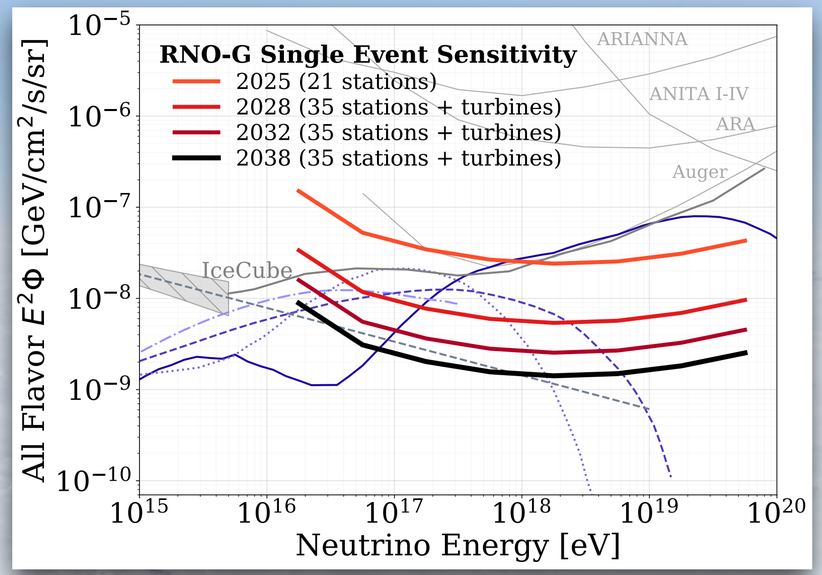




Summary & Outlook

- RNO-G is currently deploying at Summit Station in Greenland
- When completed, RNO-G will have world leading sensitivity for 1 EeV neutrinos
  - Potential to discover the first UHE neutrino!
- RNO-G will be contributing with UHE neutrino observation to multi-messenger campaigns in the Northern Hemisphere
- Current efforts focus on calibration & commissioning
  - See talks by Jethro Stoffels and Bob Oeyen this afternoon
- We are preparing for neutrino searches!





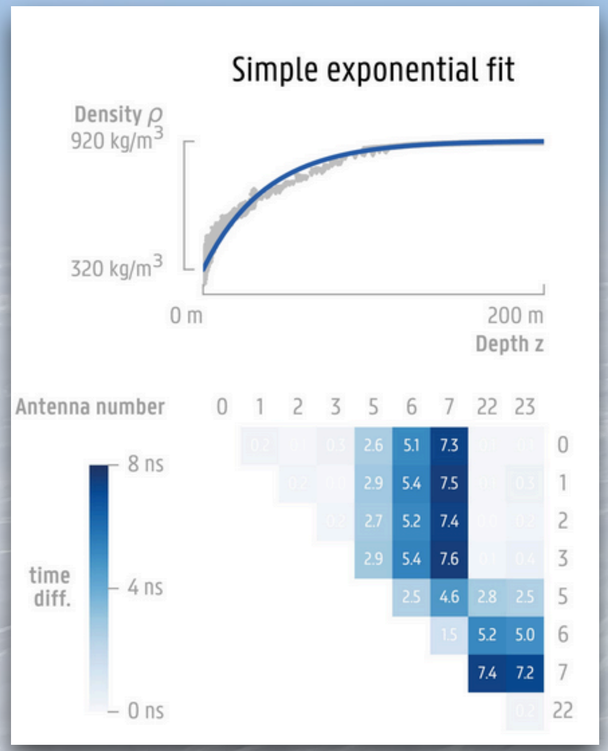
RNO-G
Collaboration
February 2023

Backup

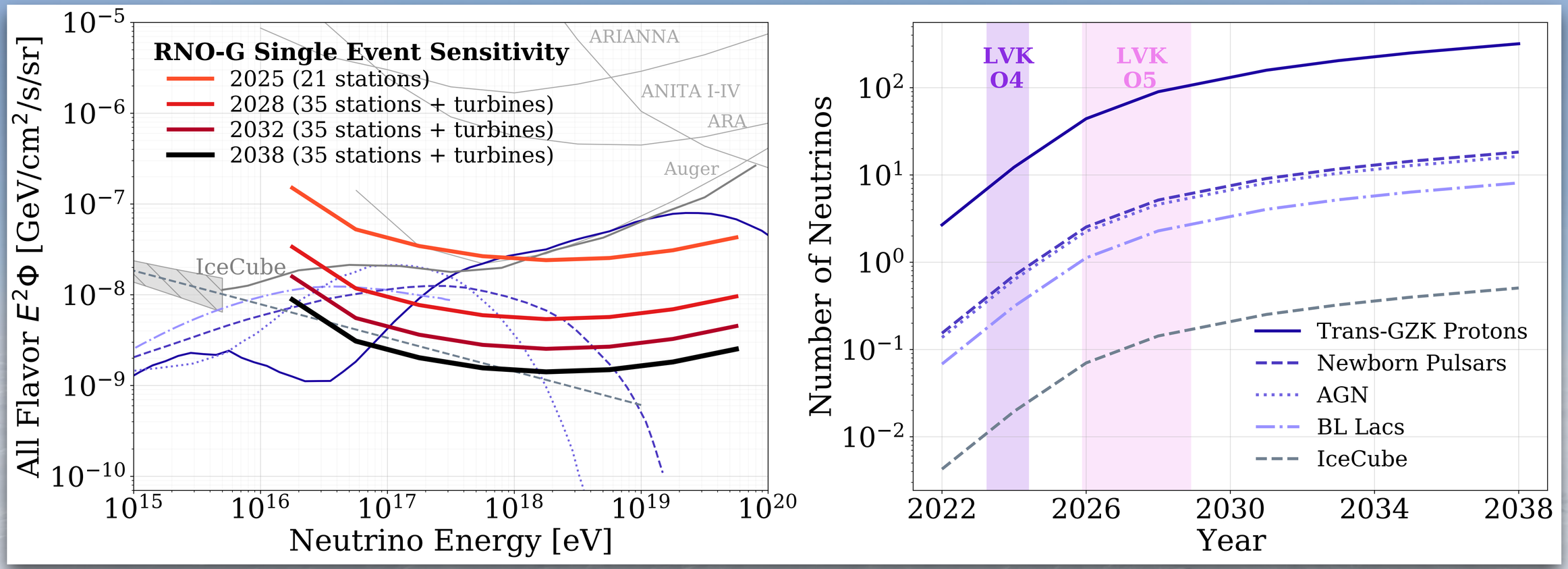
Calibration

Current effort!

- The ice is part of our detector
  - Refractive index profile of crucial importance
  - ➡ See Talk by Bob Oeyen this afternoon



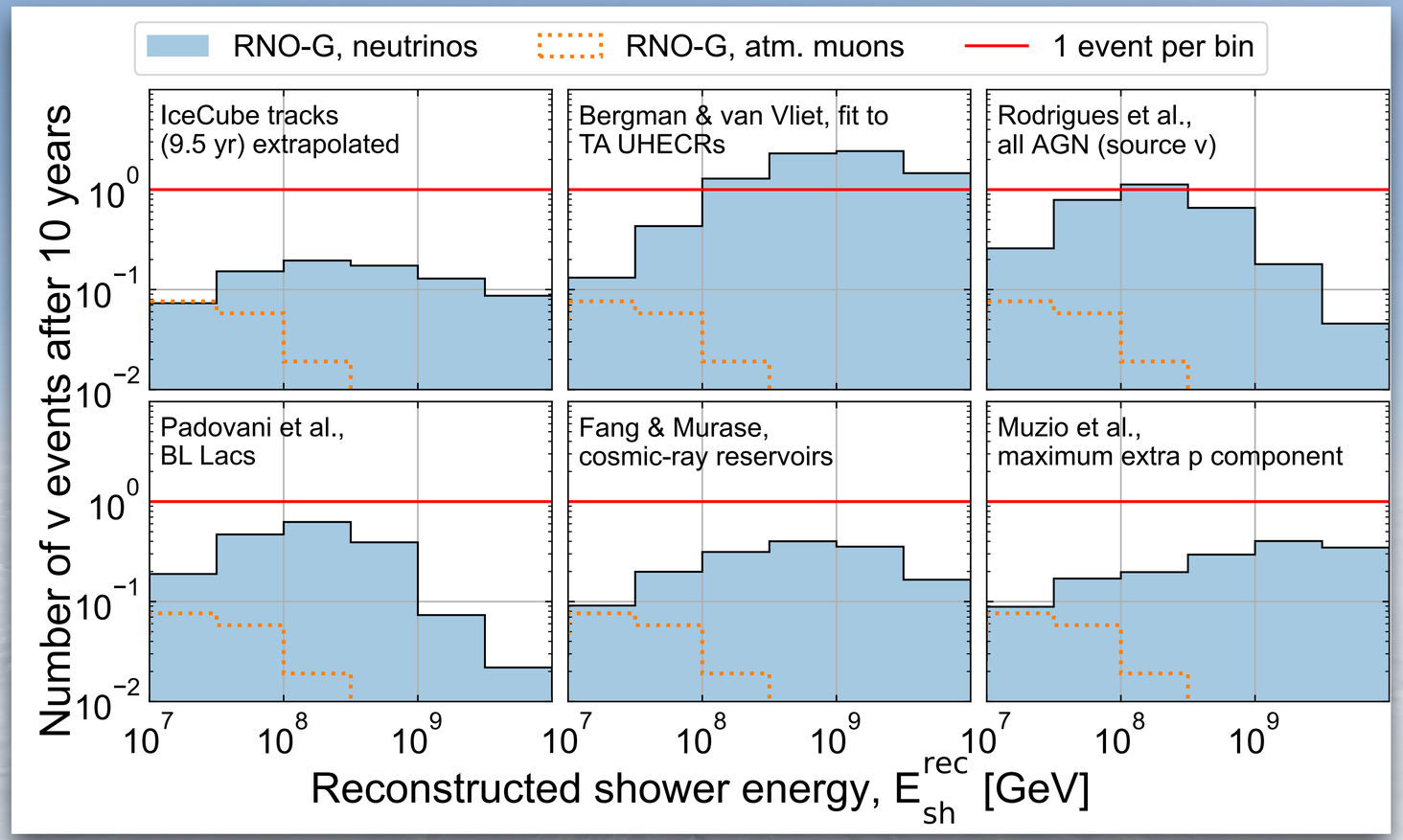
Sensitivity to different sources



Expected number of neutrinos

For different flux models

- Several models predict at least one neutrino when integrating over the energy



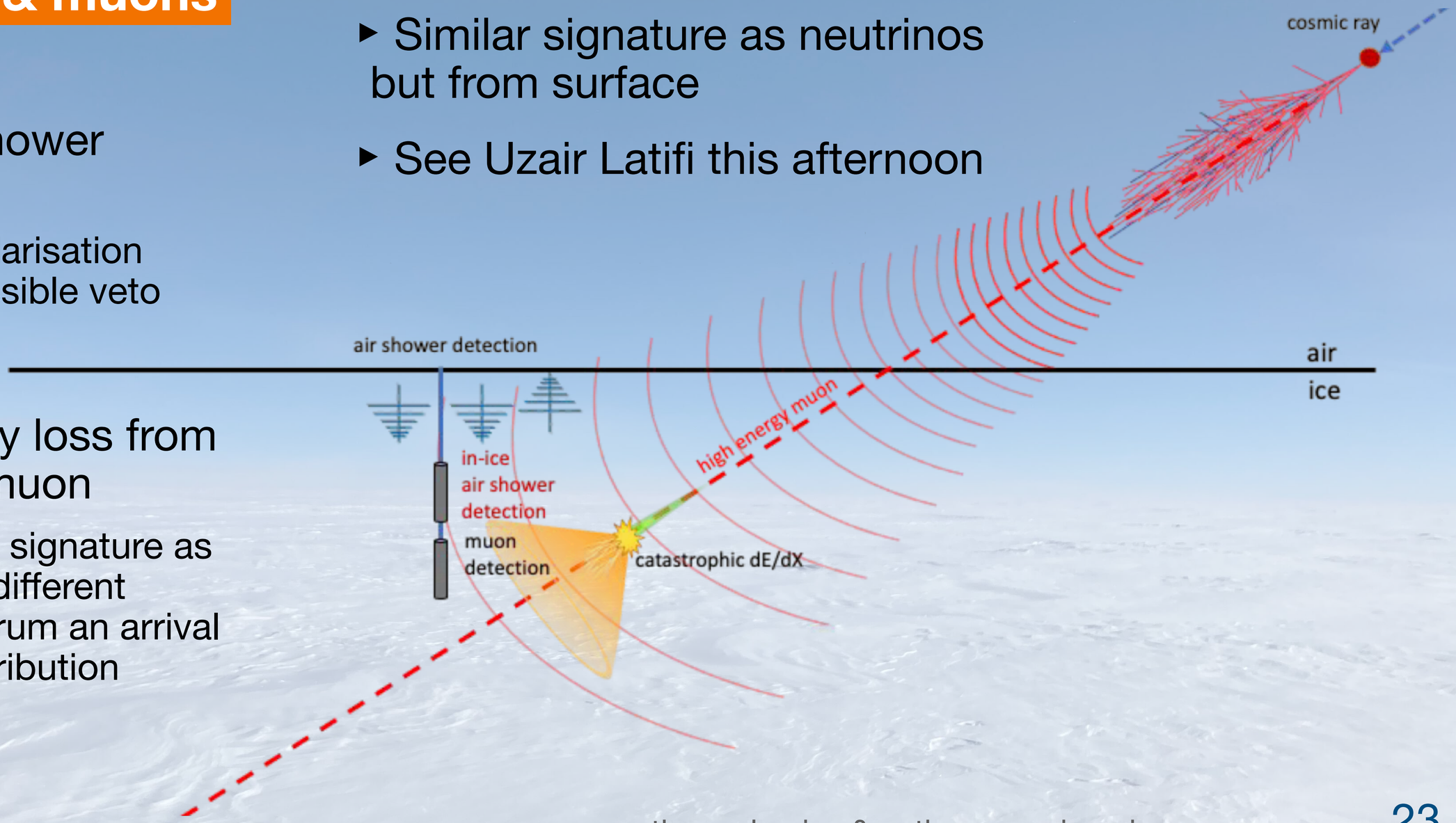
Background

Air showers & muons

1. Direct air shower emission
   - Different polarisation pattern, possible veto

2. Huge energy loss from high energy muon
   - Same signal signature as neutrino but different energy spectrum an arrival direction distribution

3. In-ice emission if air shower particles reach ice
   - Similar signature as neutrinos but from surface
   - See Uzair Latifi this afternoon

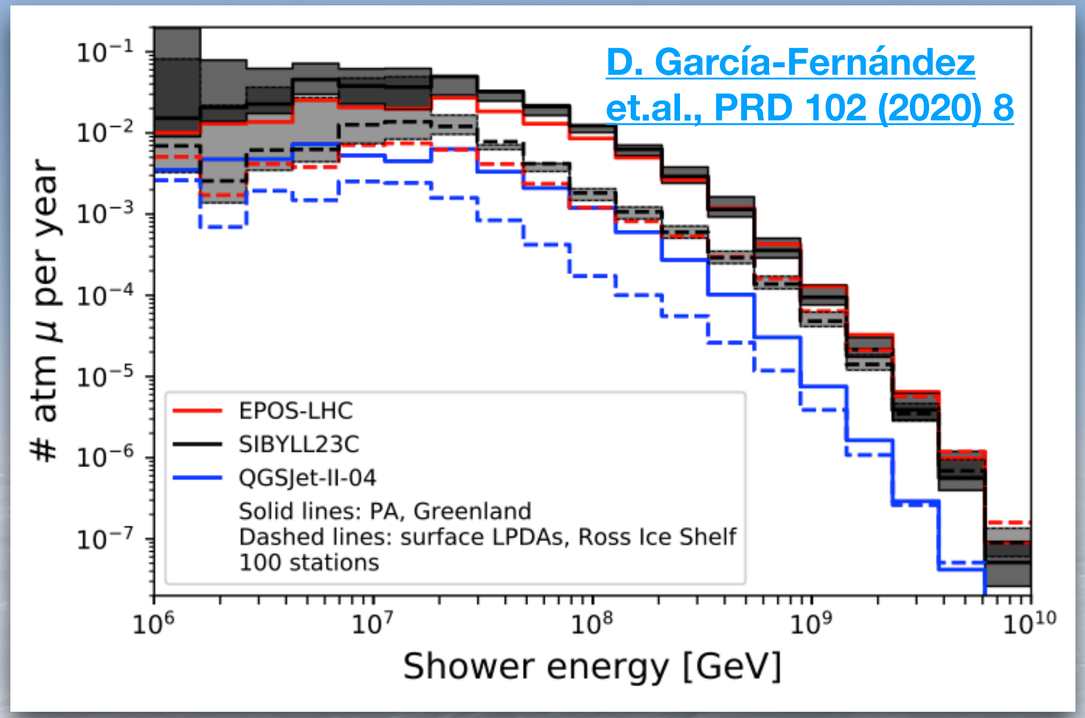


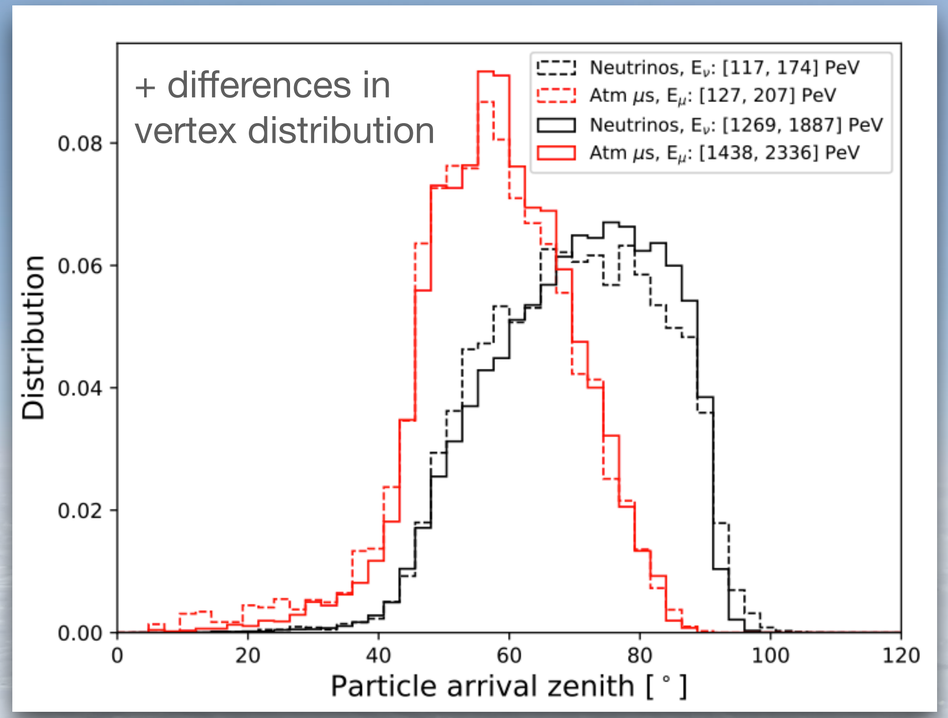
+ thermal noise & anthropogenic noise

Background

Air showers & muons

- Estimated muon background for 100 stations!

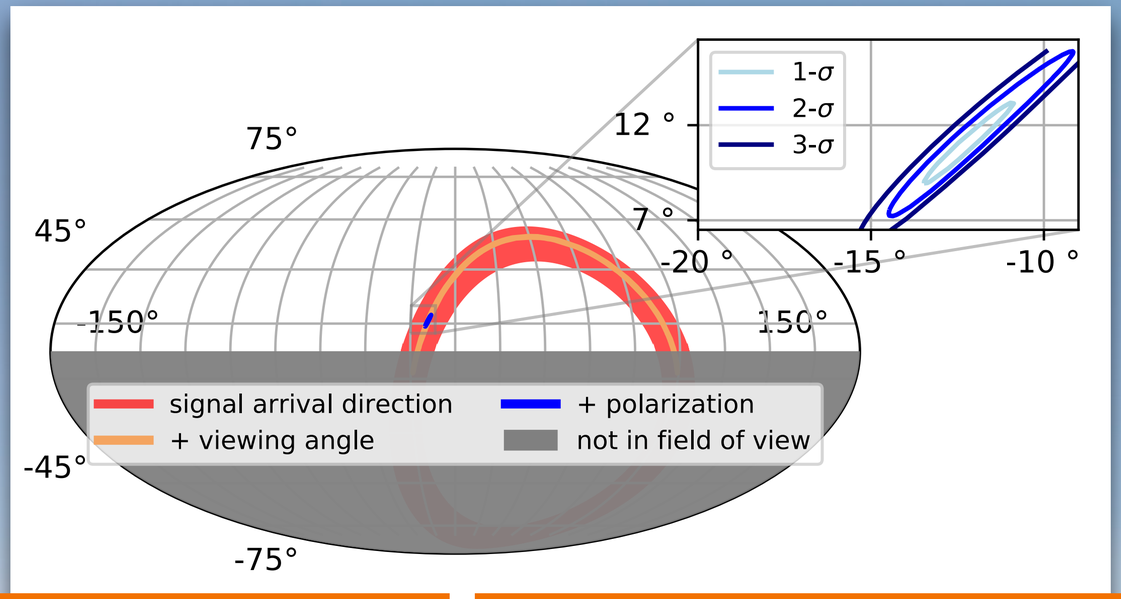




	PA 100 m
SIBYLL 2.3C	0.311
EPOS-LHC	0.185
QGSJet-II-04	0.048

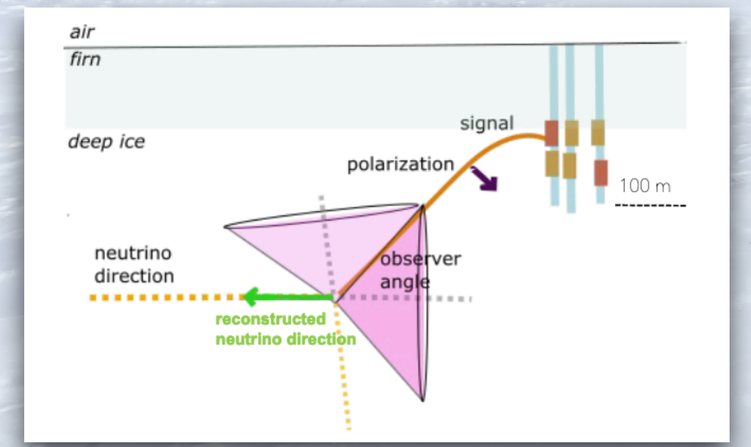
Arrival direction reconstruction

Combination of different observables

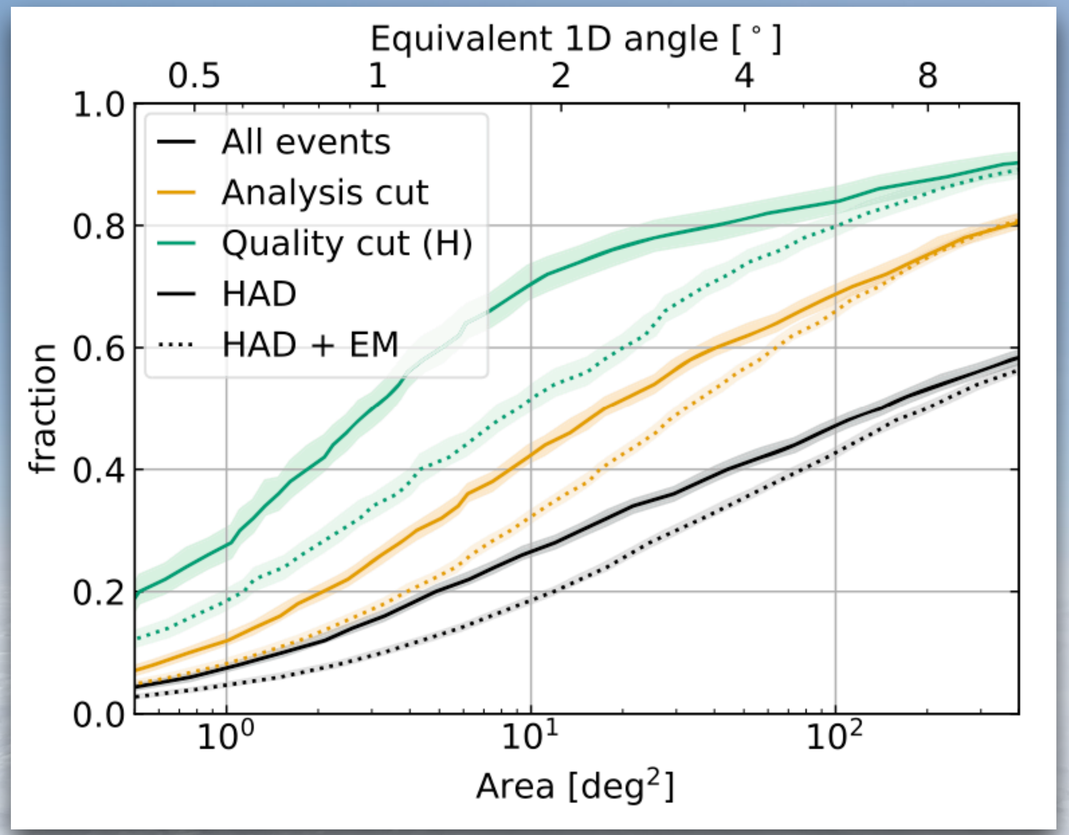


Frequency content is sensitiv to viewing angle

Polarisation tells you “where on the cone you are”



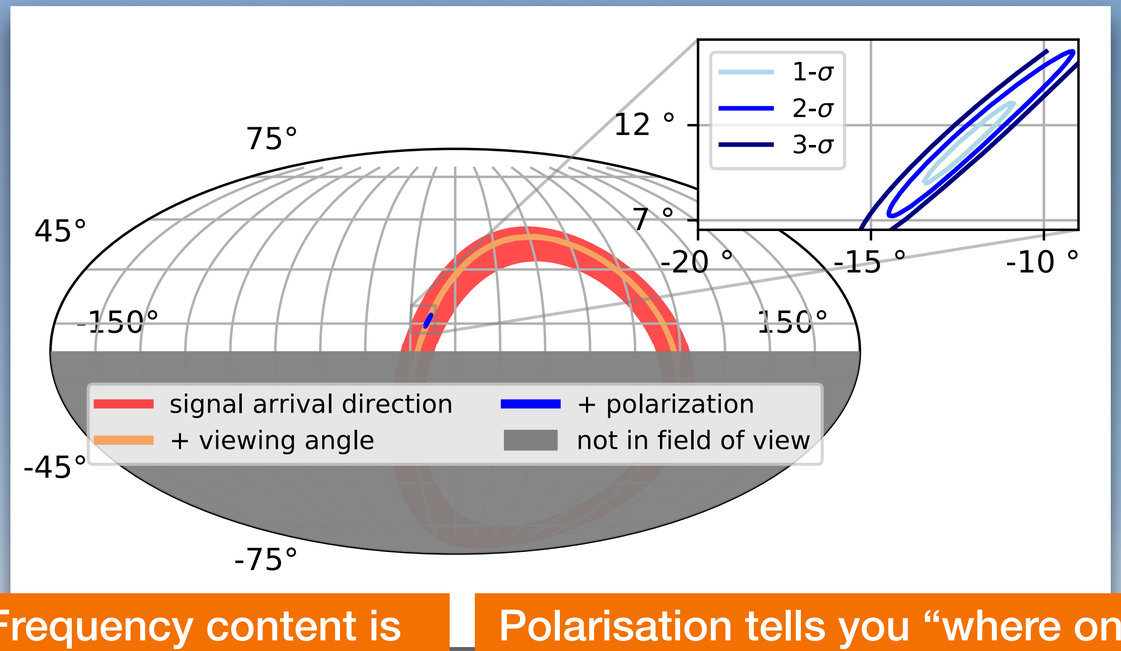
Results (for deep antennas only)



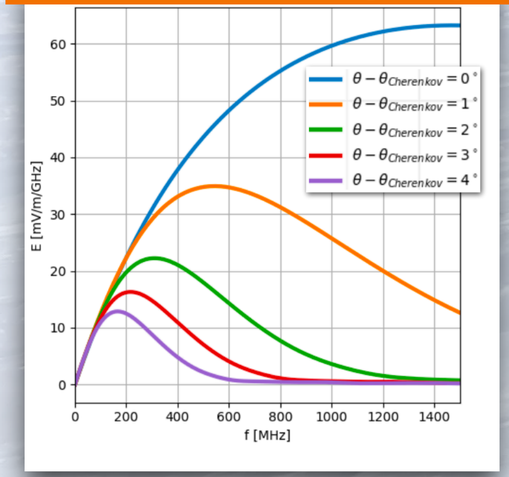
[I. Plaisier et.al., EPJC 83 (2023) 5]

Arrival direction reconstruction

Combination of different observables



Frequency content is sensitiv to viewing angle



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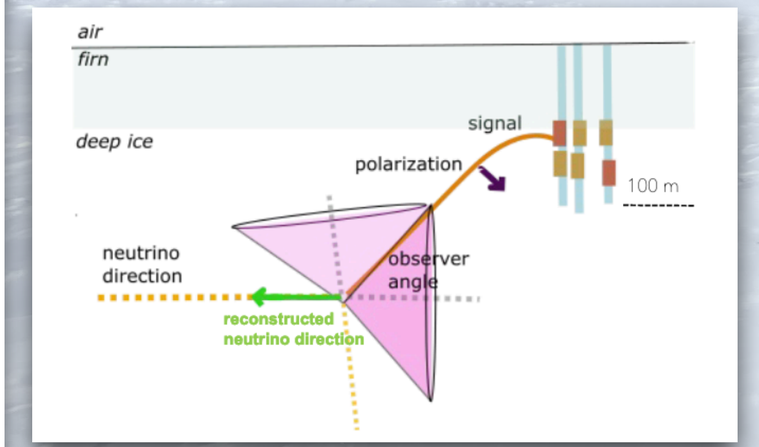

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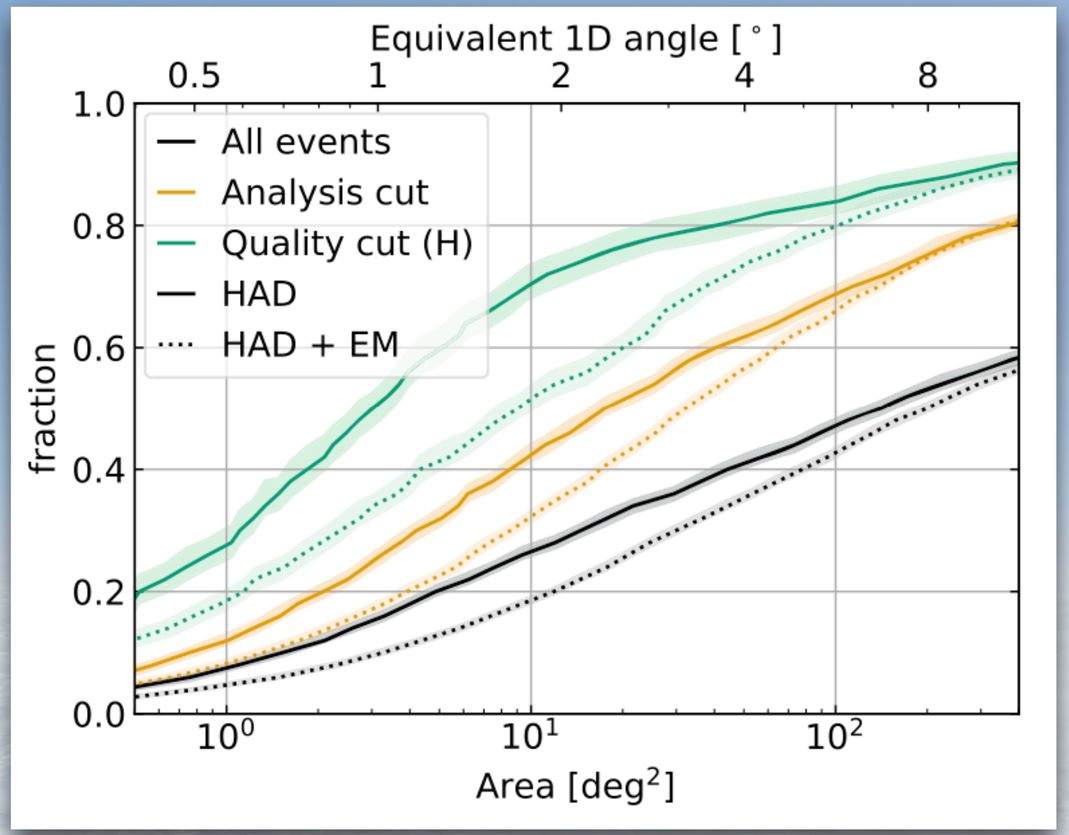


[I. Plaisier et.al., EPJC 83 (2023) 5]

Energy reconstruction

- Recipe: Signal strength, polarisation, viewing angle, vertex distance

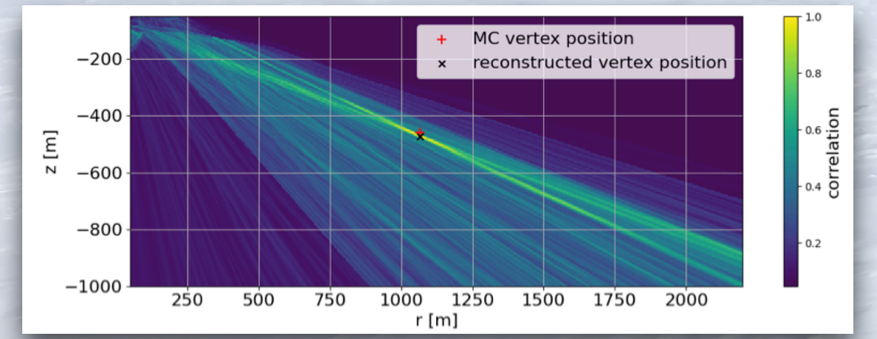
Shower Energy
(Depends on E_ν)

Neutrino Direction

$$\vec{\mathcal{E}}(f) \propto (1-y)E_\nu \underbrace{\exp\left[-\frac{1}{2}\left(\frac{\theta-\theta_c}{\sigma(E_{sh},f)}\right)^2\right] \frac{1}{R}\exp\left(\frac{-R}{L(f)}\right)}_{\text{(Depends on) Vertex Position}} \underbrace{\vec{\ell}\times(\vec{v}_\nu\times\vec{\ell})}_{\text{Polarization}}$$

Observed Field

Vertex reconstruction



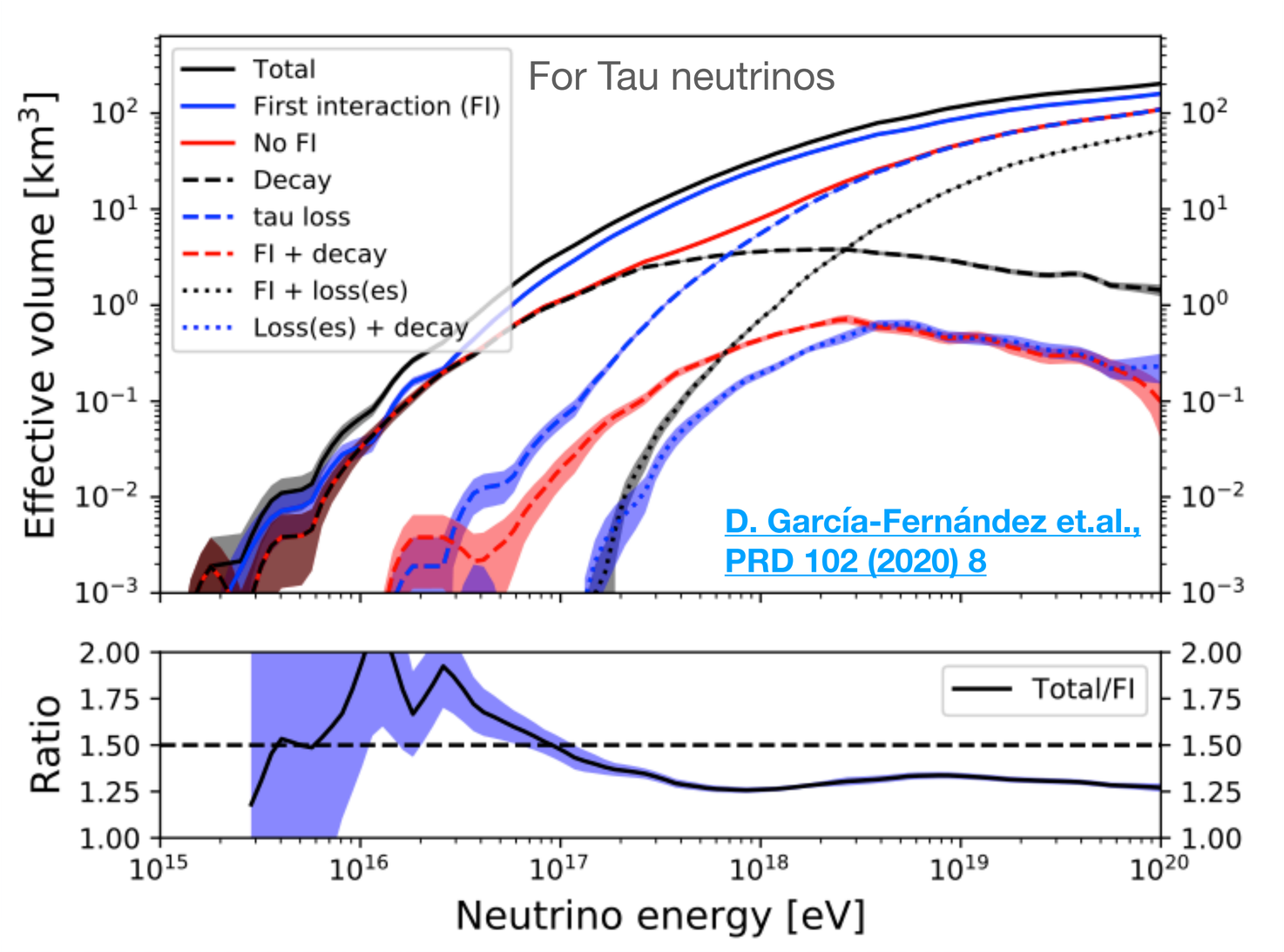
RNO-G, JINST 16 (2021) 03 RNO-G, EPJC 82, 147 (2022)

Ice Properties

- Part of the detector -> needs to be calibrated

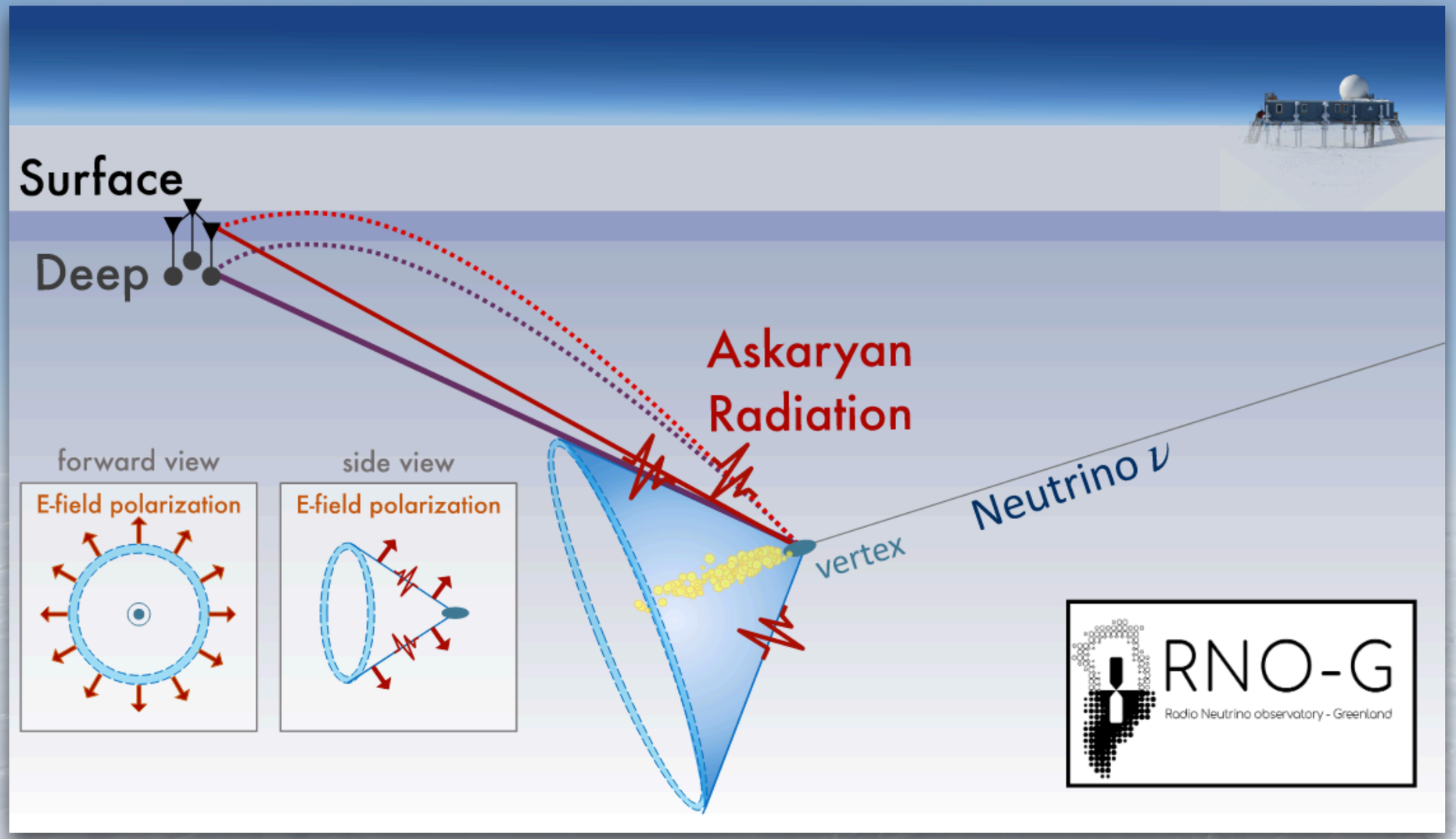
Signals from secondary leptons

Which undergo catastrophic energy losses



Askaryan Radiation

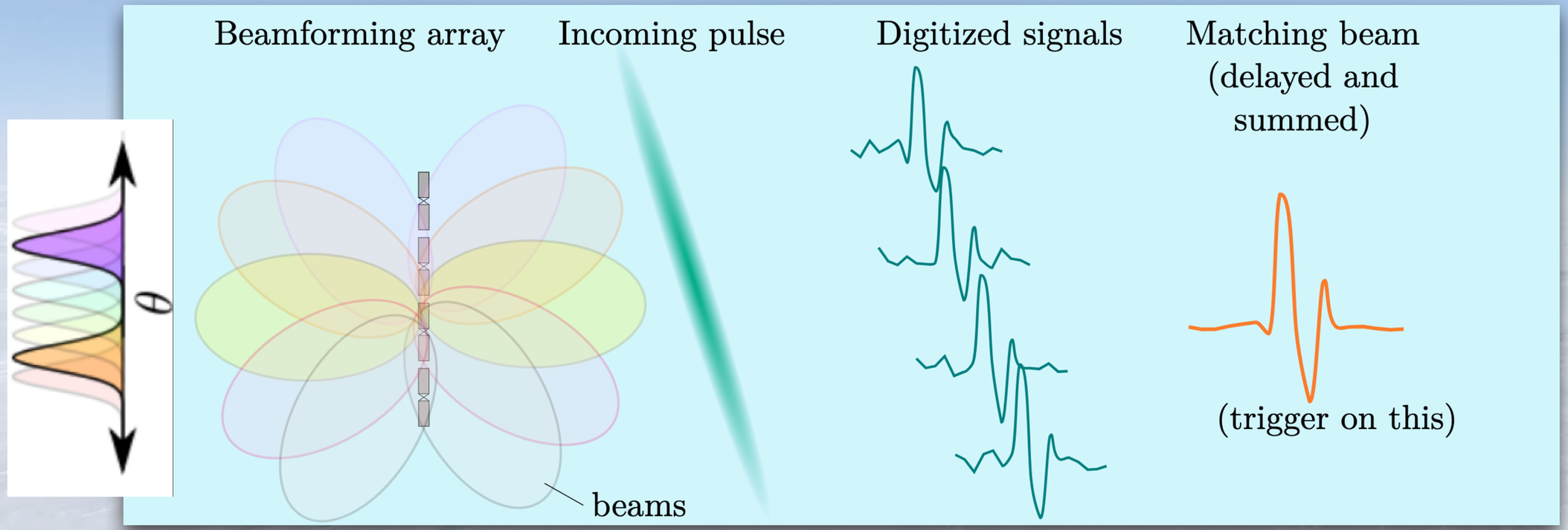
Specific polarisation pattern



Phased array

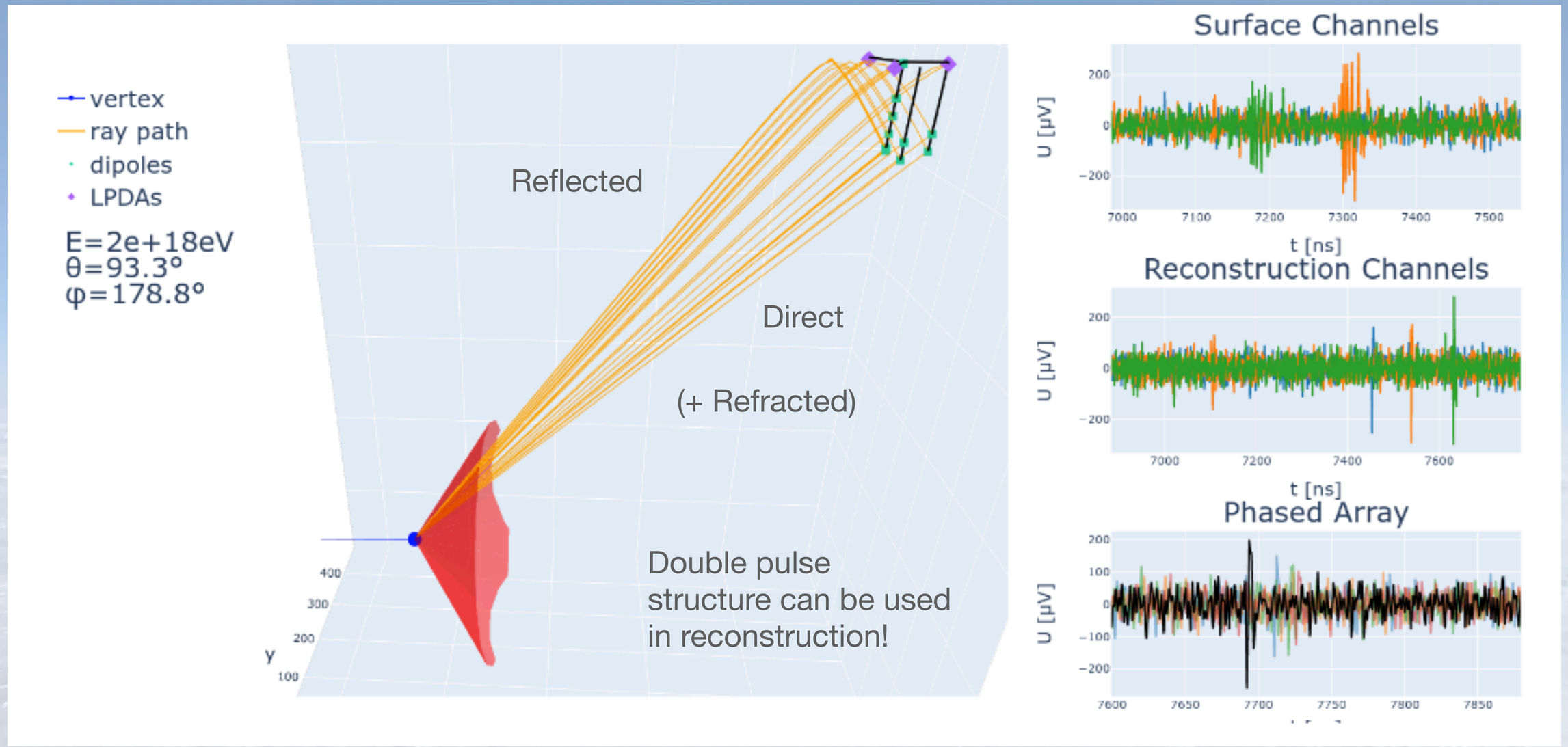
For triggering and reconstruction

- Trigger runs on lower bandwidth (< 250 MHz), 8 beams are formed
- Design goal for threshold: amplitude_signal / sigma_noise = 2
- Technique demonstrated at South Pole by ARA [ARA, PRD 105]



Propagation

Signal can reach antennas on different trajectories!

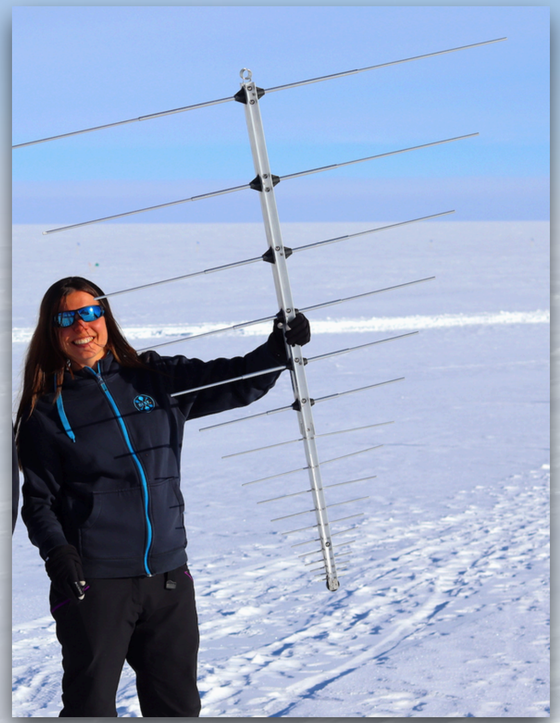


Antenna sensitivity

3 different antenna types

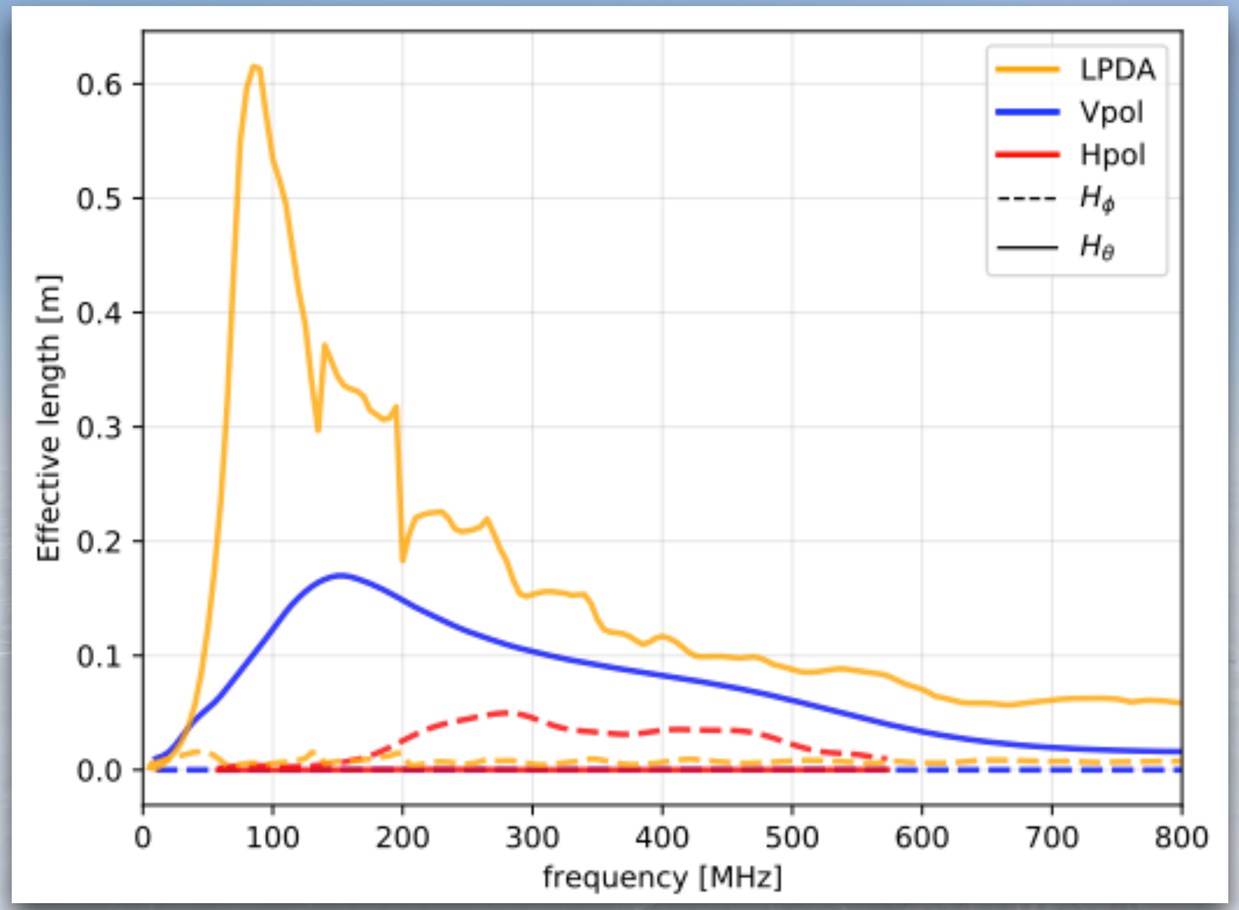
- LPDA is more sensitive but can not be deployed in borehole
- HPol is less sensitive because of narrow diameter of borehole

LPDA

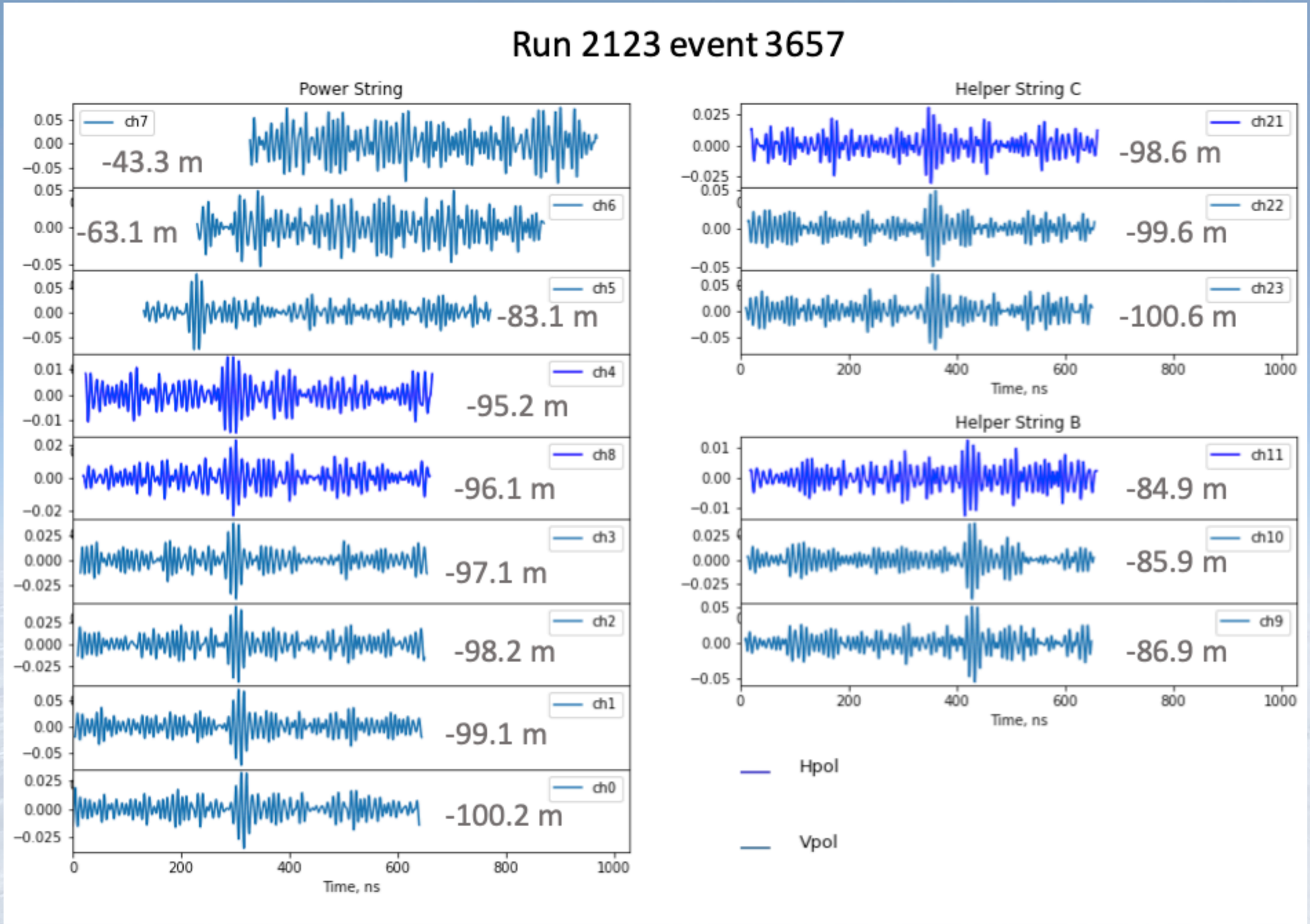


Hpol

Vpol



Solar flare


Run 2123 event 3657
Power String
ch7
-43.3 m
ch6
-63.1 m
ch5
-83.1 m
ch4
-95.2 m
ch8
-96.1 m
ch3
-97.1 m
ch2
-98.2 m
ch1
-99.1 m
ch0
-100.2 m
Time, ns
Helper String C
ch21
-98.6 m
ch22
-99.6 m
ch23
-100.6 m
Time, ns
Helper String B
ch11
-84.9 m
ch10
-85.9 m
ch9
-86.9 m
Time, ns
Hpol
Vpol