IceCube: Reaching out to higher energies

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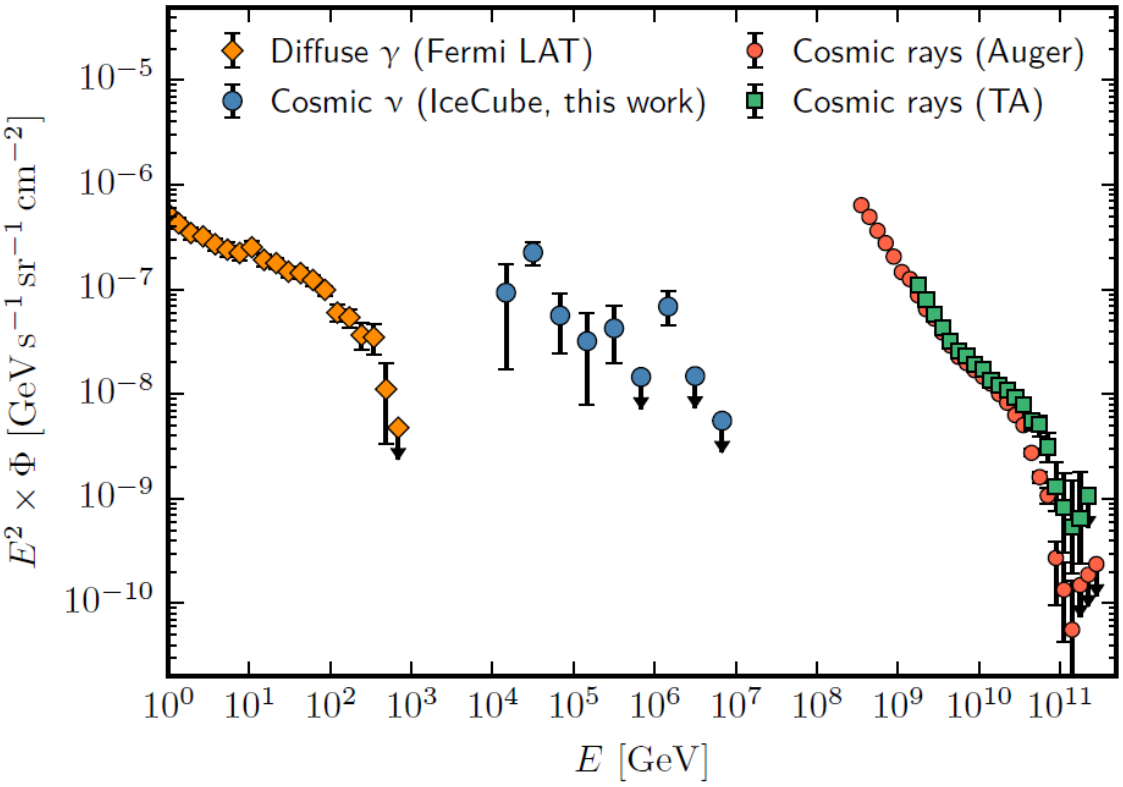
Overview

The Physics Case



- **Common astrophysical sources ?**

  $N + \gamma \rightarrow \Delta \rightarrow \pi + N$ **(CR)** $\quad \pi^0 \rightarrow \gamma\gamma$ **(Fermi)** $\quad \pi^{\pm} \rightarrow \nu, \bar{\nu}$ **(IceCube)**

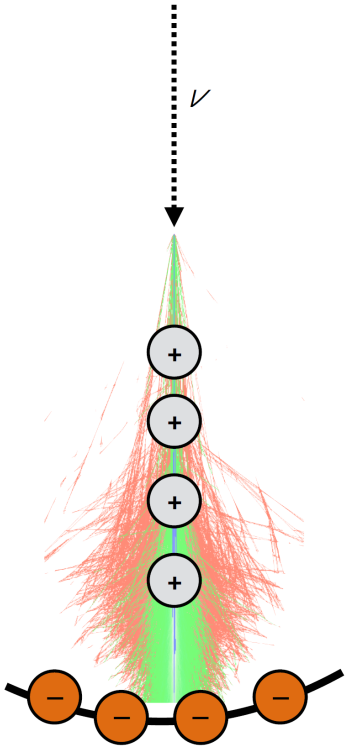
- **Cosmic ν spectrum ? $\rightarrow$ Need more (multi) PeV data**
- **$E_\nu \approx 4\%$ of $E_N \rightarrow$ Search for 10^{18}eV (GZK) neutrinos**

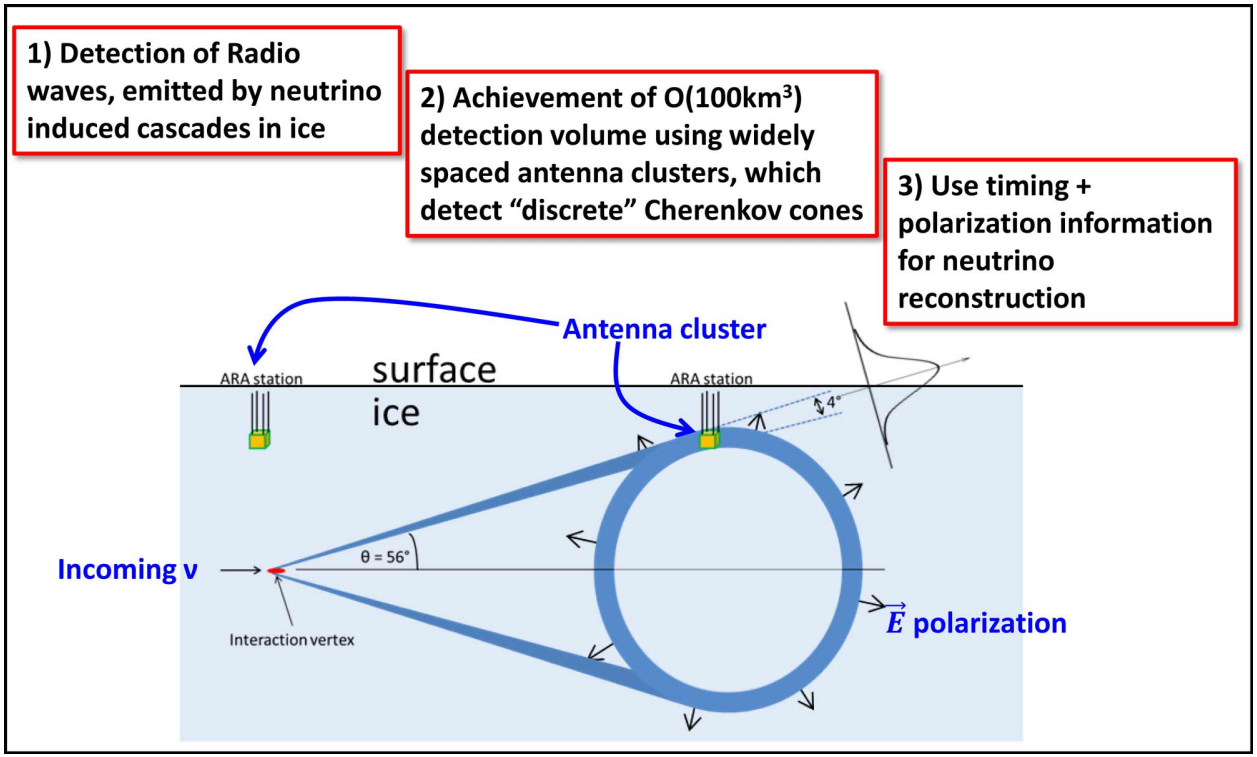
Radio Detection

- Current 1 km^2 IceCube detector is too small for the low >PeV fluxes
  ∼5 events ∼PeV detected in 10 years → Need >100 times larger detector
  $\lambda_{att} \sim 200$m for light → Amount of light sensors and drilling not feasible

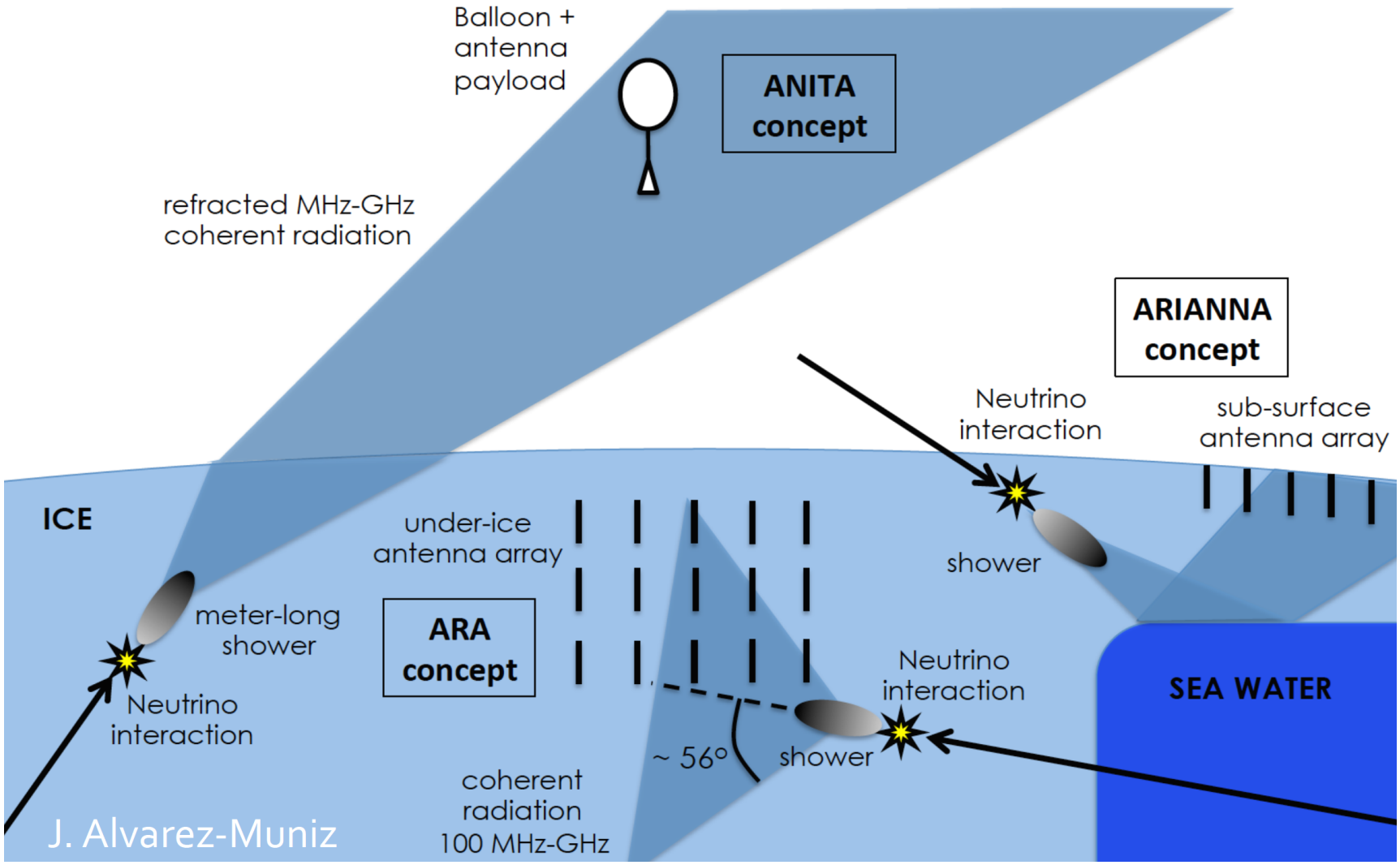
Radio signals of ν showers

- Long (km-scale) λ_{att} → Cost effective way to cover large (∼500 km^2) area

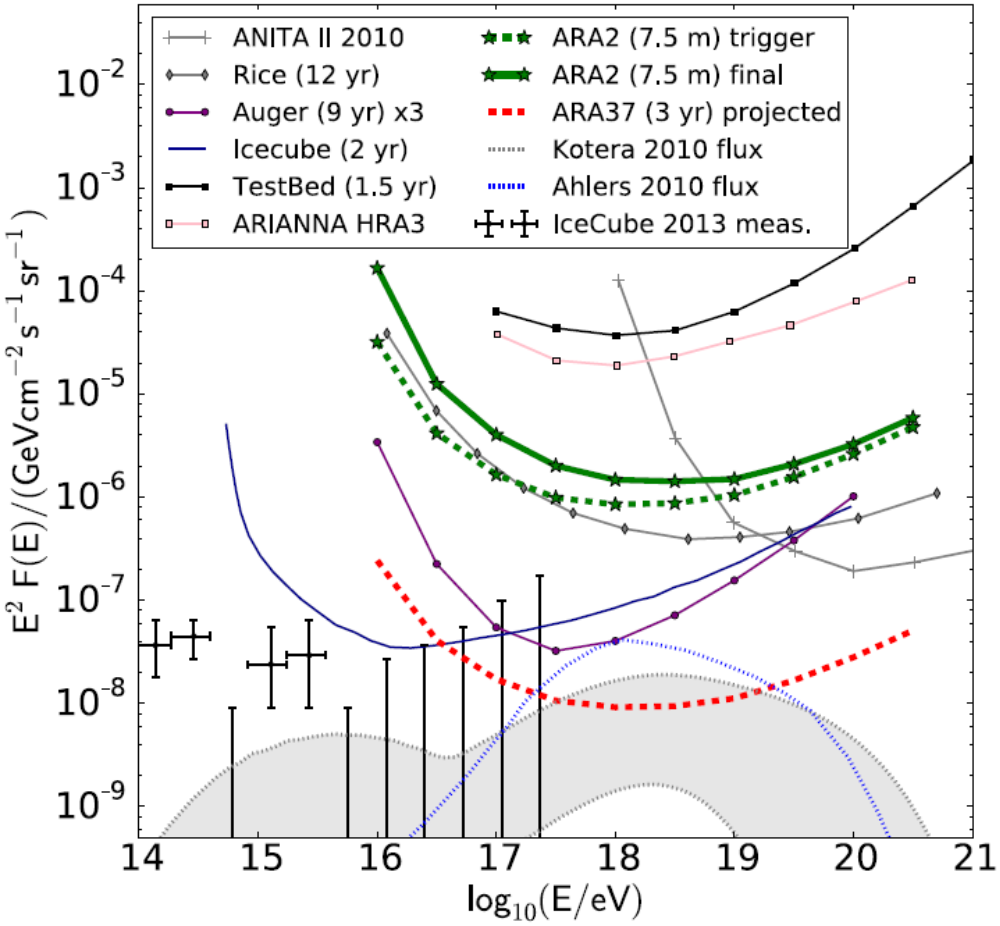




Currently (pilot) projects are taking data : ANITA, ARA and ARIANNA



The multi-PeV neutrino landscape



Prospects for radio detection

- Detect events $> 10^{17}$ eV (100 PeV)

  GZK ν : Proof of GZK effect

  or : **Insight in UHECR composition**

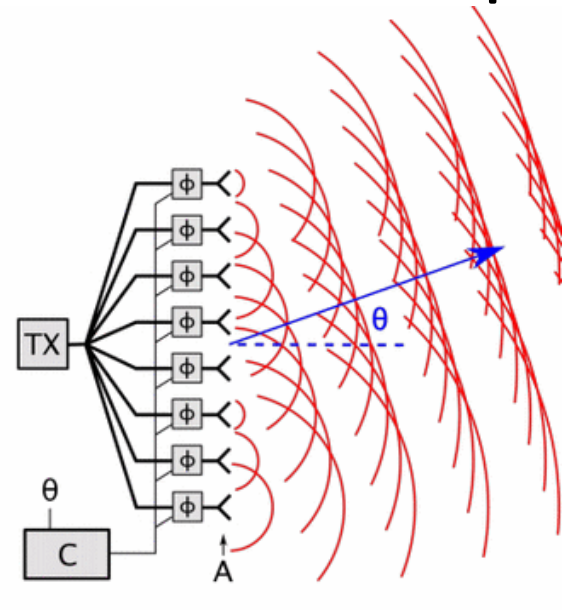
* **IceCube-Radio energy gap**

  Currently not covered

Try to lower the energy threshold

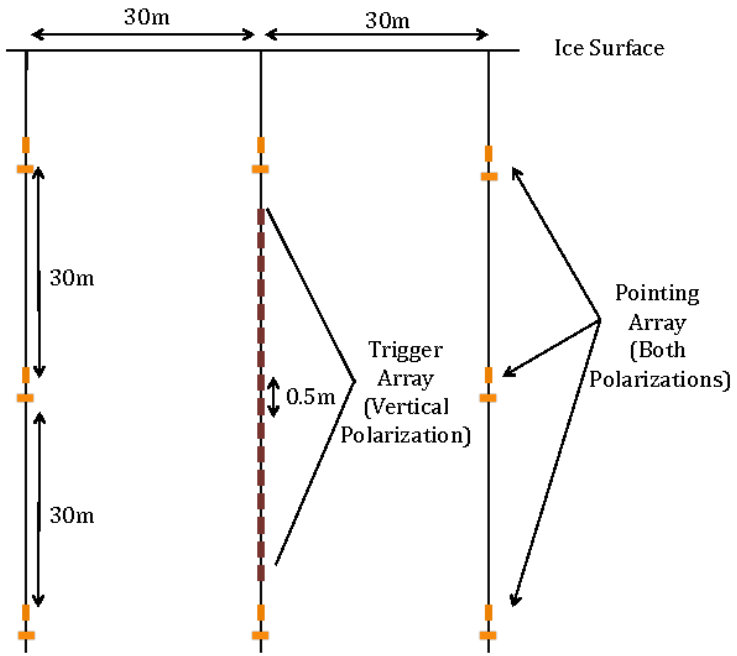
The phased array trigger approach

Well known technique



- Similar for receiving signals (e.g. radio astronomy)
- Using multiple beams
  → Directional sensitivity

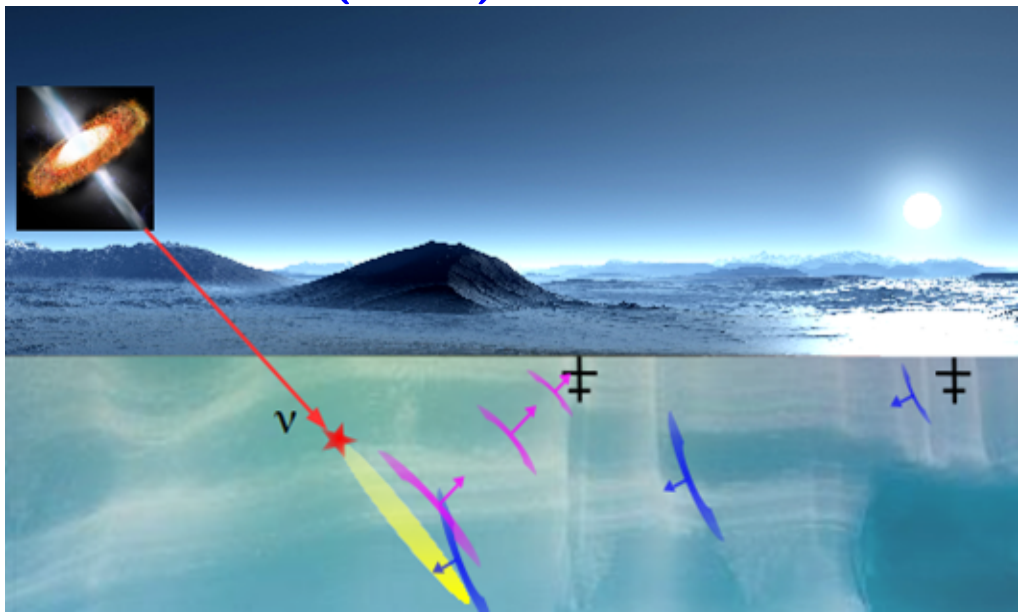
Testbed currently taking data



- Provide trigger to ARA antennas
  Directional info → Reduce noise
  Lower ARA threshold for ν detection

Radar reflections from the shower plasma

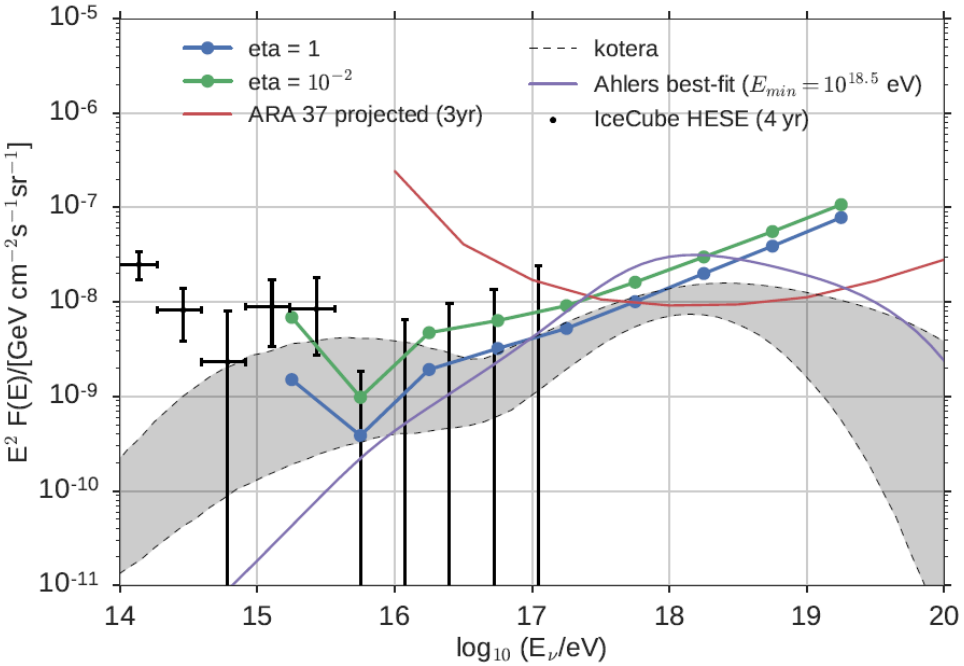
New idea (VUB) for $E < 10^{17}$ eV



[Credit Krijn de Vries]

Simulation results

[arXiv:1802.05543]



- **Signal scales with transmit power**
  $\rightarrow$ Allows low energy threshold
- **Testbed currently under (beam)test**

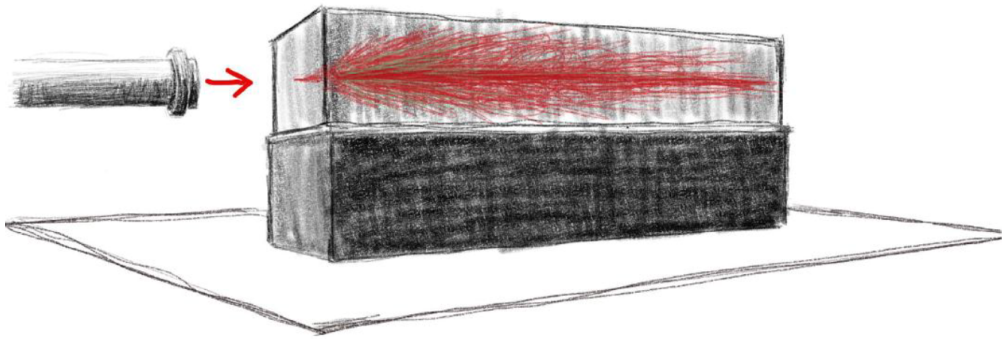
Fills the IceCube-Radio E gap

- **Radar+ARA $\rightarrow$ Full energy coverage**

FIRST OBSERVATION OF A RADAR SCATTER FROM A PARTICLE SHOWER

SLAC T-576

Fig.: S.Prohira



- As the beam enters the target, a cascade is created in the material

ICRC2019--31.7.19 neutrino radar T576--steven prohira CCAPP

Observation of Radar Echoes From High-Energy Particle Cascades

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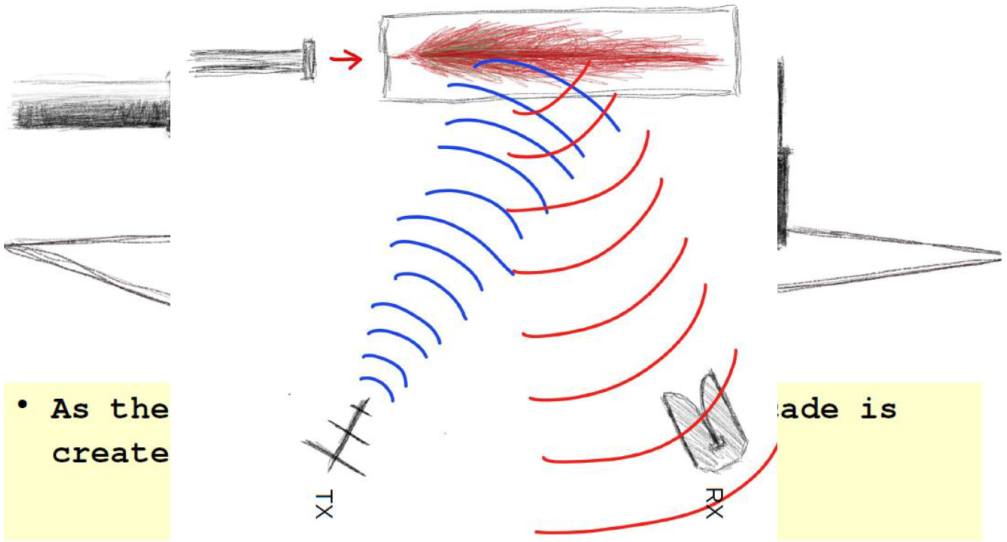

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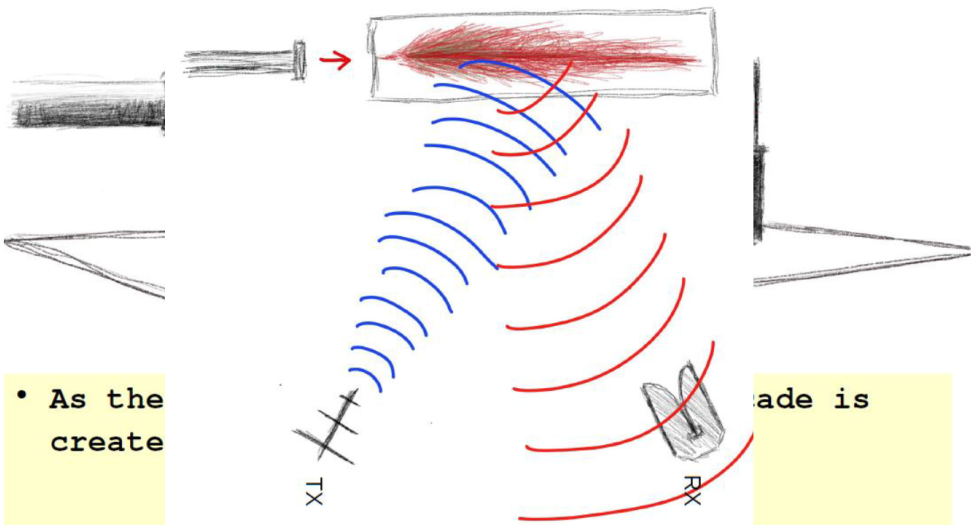

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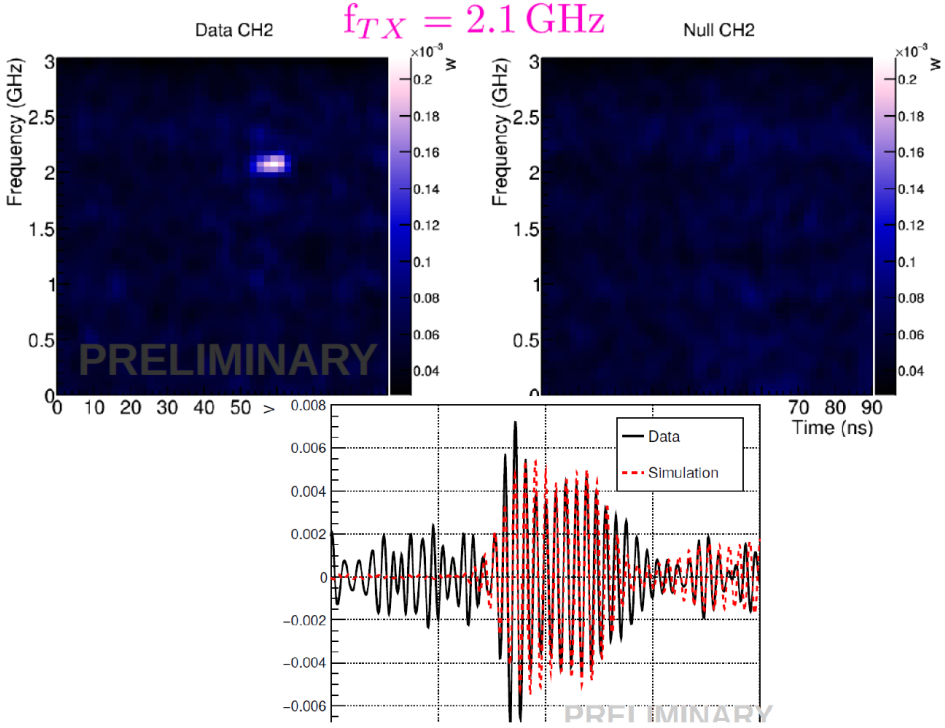
$f_{TX} = 2.1\,\mathrm{GHz}$



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WHAT'S NEXT: THE AIR SHOWER CORE IN ICE

NARROW HIGH ENERGY CORE

Air EM profile:
10 km length
100 m width

Ice EM profile:
10 m length
10 cm width

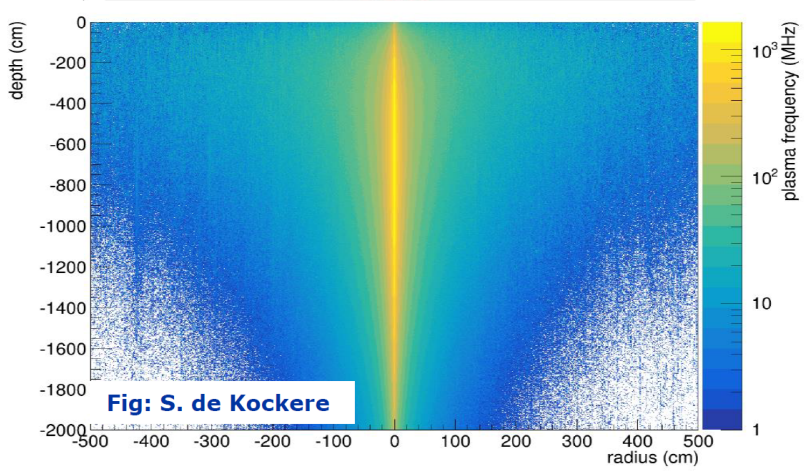


Fig: S. de Kockere

PROOF OF CONCEPT FOR RADAR DETECT THE AIR SHOWER CORE IN ICE

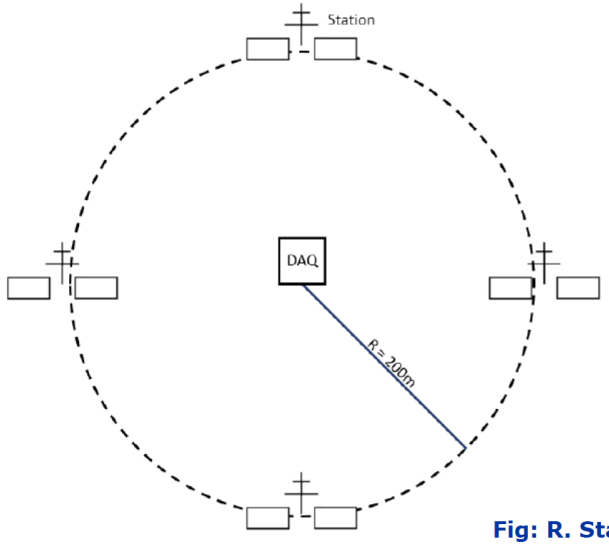
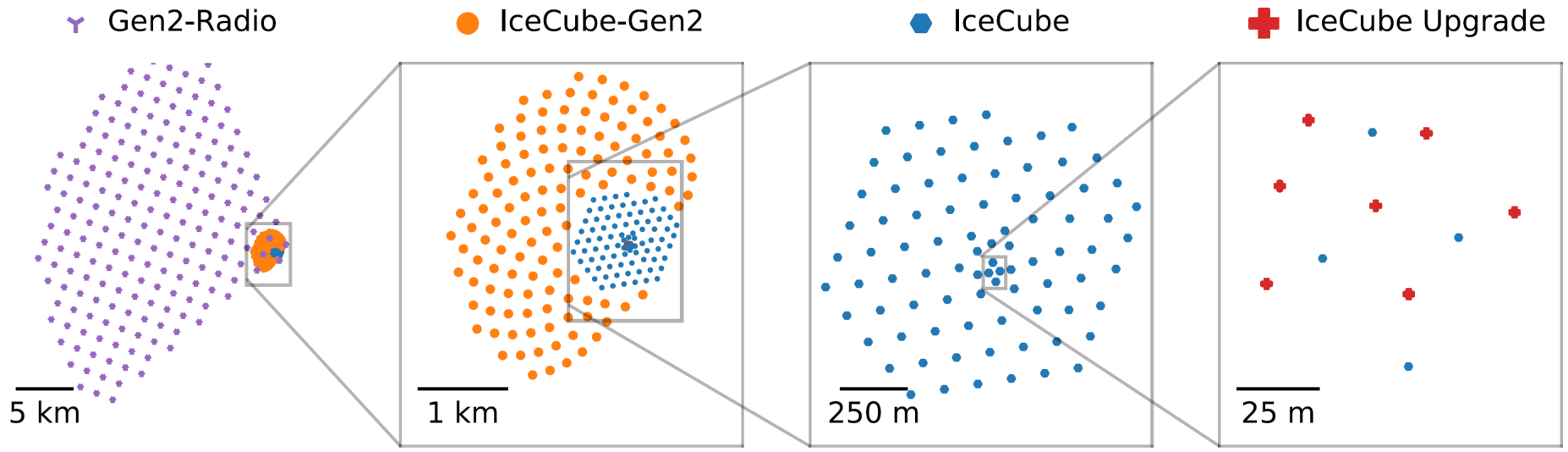


Fig: R. Stanley, K. Mulrey

Krijn de Vries, Nick van Eijndhoven, Simona Toscano, Katie Mulrey, Simon de Kockere, Rose Stanley, Enrique Huesca, Dieder van den Broeck

The IceCube High-Energy Extension

The IceCube-Gen2 extended neutrino observatory



- Radio component : $\sim$200 stations covering $\sim$500 km^2
- Autonomous power and communication
- Never been tried before in polar conditions $\rightarrow$ Need for a pathfinder project
  - Test autonomous power and communication
  - Test scalability towards $\sim$200 stations
  - Provide initial scientific exploration

The Greenland Project

Pathfinder for Gen2-radio

- **IIHE is the main player**

  (Chicago, PSU, OSU, UW, DESY)
- **Location: Summit station Greenland**

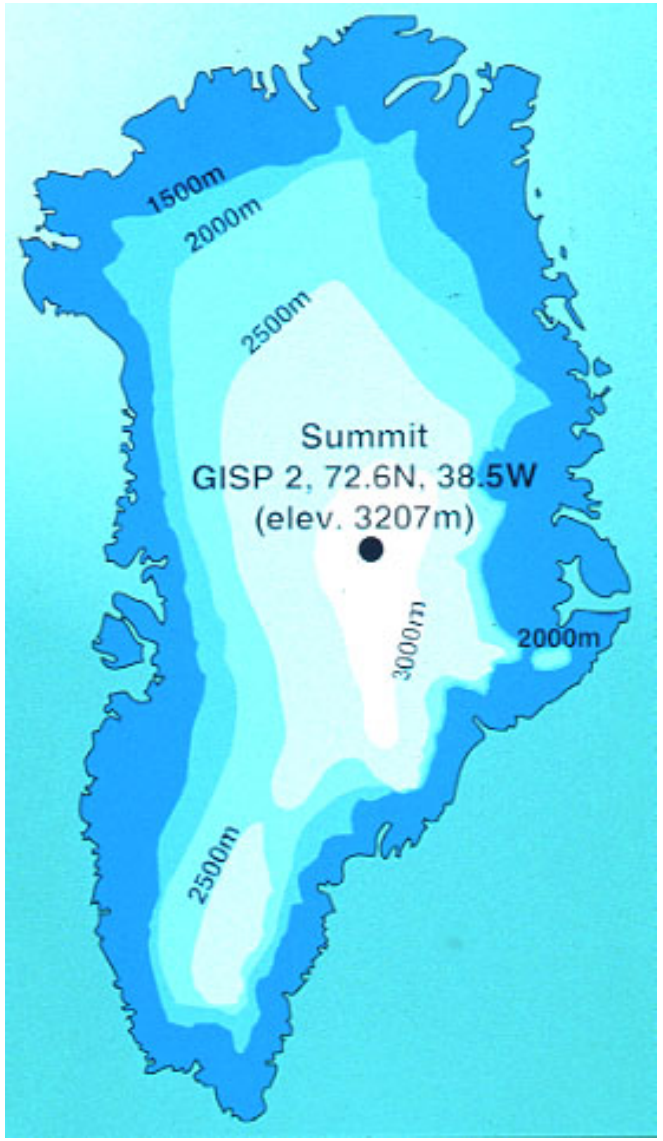
  $\rightarrow$ Inverted seasons w.r.t. SP

  No interference with IC Upgrade

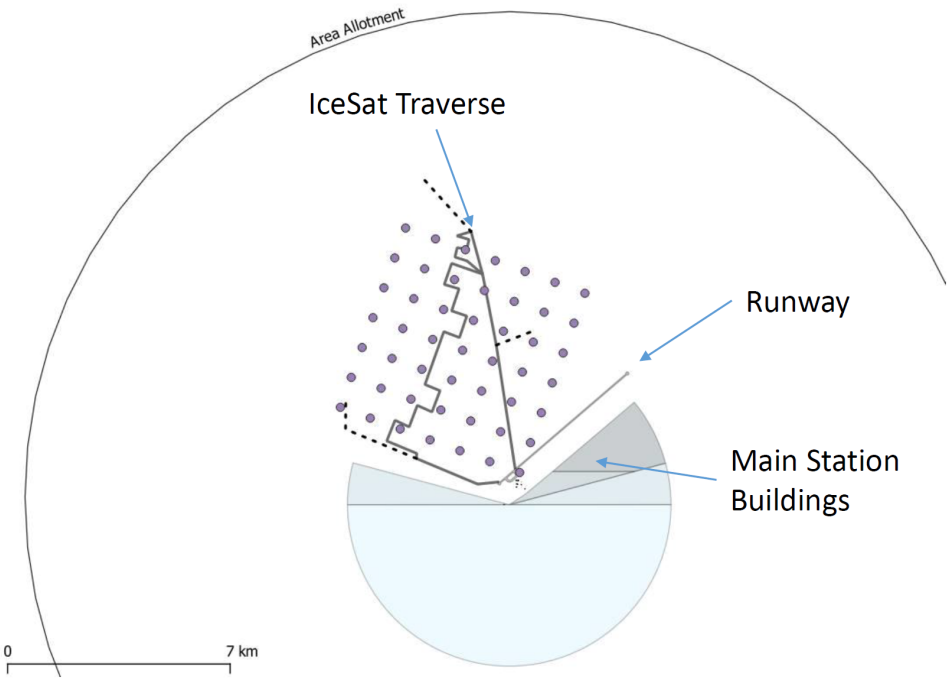
  Same NSF cargo planes etc. available
- **$\sim$45 autonomous stations in 2023**

  $\rightarrow\sim$50 km^2 array

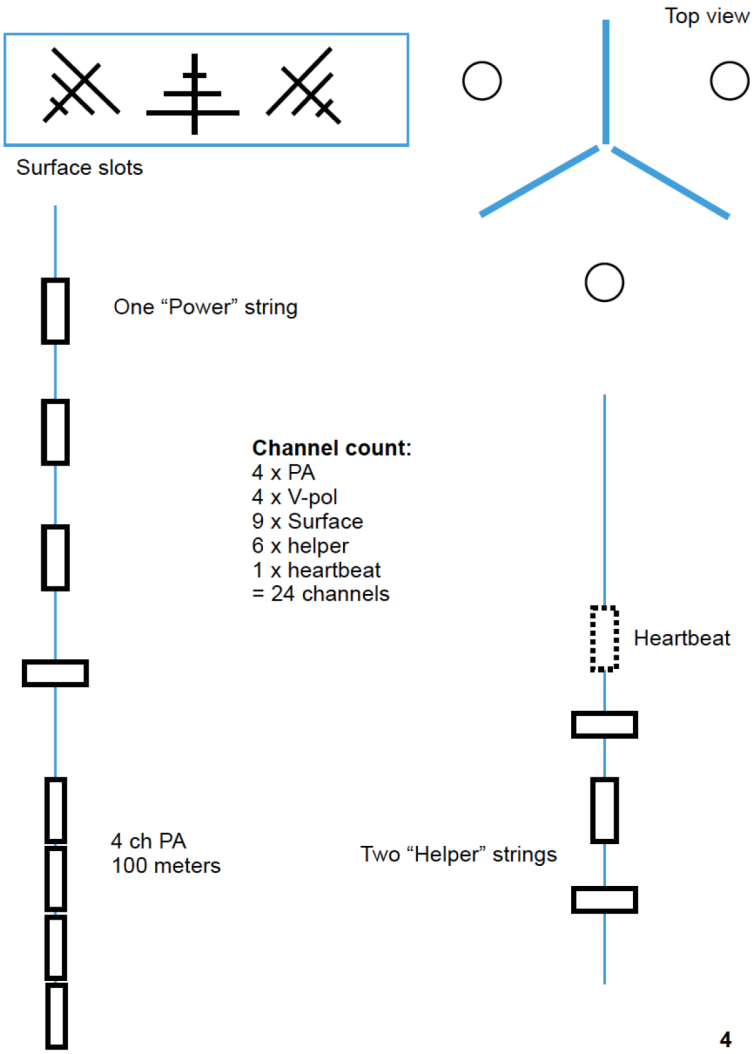
  1st deployment in 2020 (5 stations)



Array geometry



Station layout



The Greenland Project

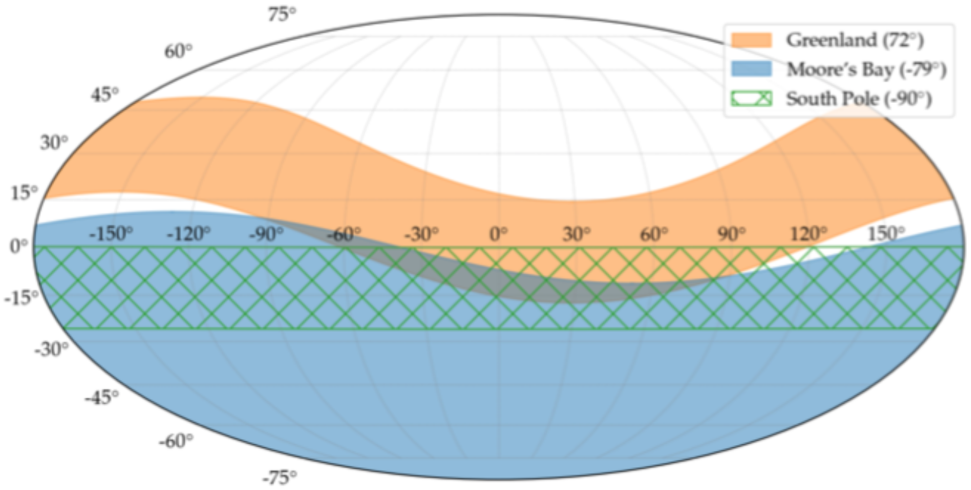
Also strong science case

- **Overlapping FoV with IC optical**

  Same location seen at PeV and TeV

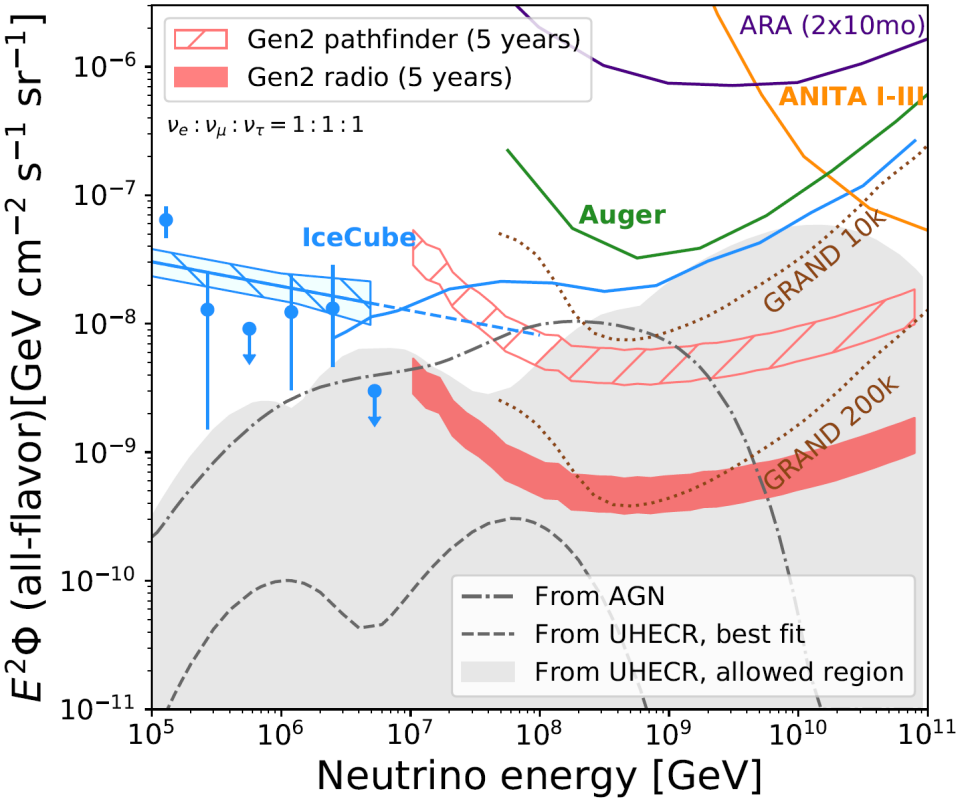
- **Complementary FoV to SP radio**

  Earth rotation: Larger sky coverage



(Equatorial coordinates)

Sensitivity



Summary and Outlook

- Need for more statistics of cosmic ν at $>$PeV energies
  - Study spectral characteristics of high-energy cosmic ν
  - Investigate/confirm the GZK effect
- Need for $>$100 times the current IceCube size
  - Only feasible with detection via radio signals ($\lambda_{att} \sim$1 km)
  - Radio component of $\sim$500 km^2 planned for IceCube-Gen2
- Pathfinder project started for a $\sim$50 km^2 radio array in Greenland
  - Test technical aspects (low threshold, autonomous operation, scalability)
  - First physics exploration of unknown energy regime (GZK neutrinos)

  IIHE has taken a lead in the pathfinder project (5M FWO-IRI grant)
  - First deployment of 5 stations in 2020 $\rightarrow\sim$50 stations in 2023

  Development of radar reflection technique (2M ERC-StG of Krijn)
- IIHE people involved :

  Katie, Rose, Simona, Dieder, Enrique, Juanan, Krijn, Olaf, Simon, Stijn, Nick