

Multi-PeV Neutrinos on the Rocks

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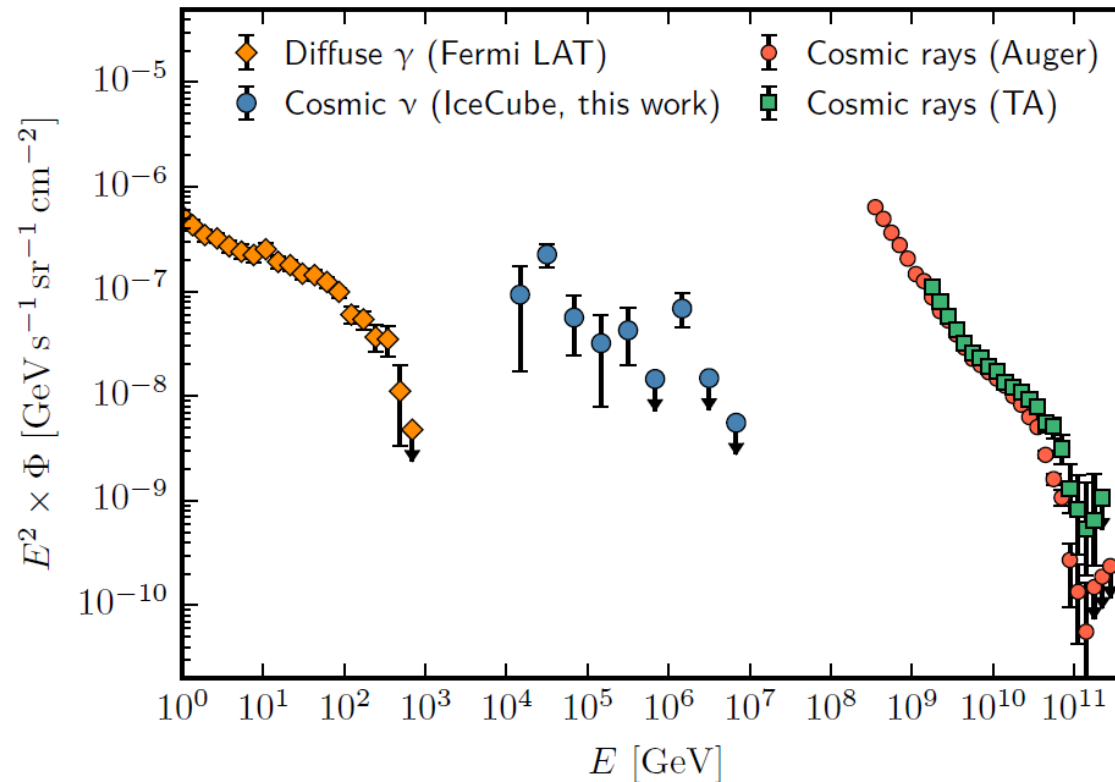
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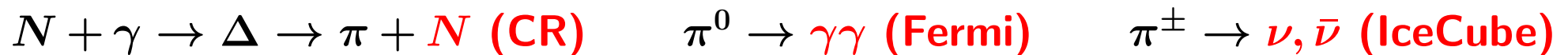


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- **Common astrophysical sources ?**



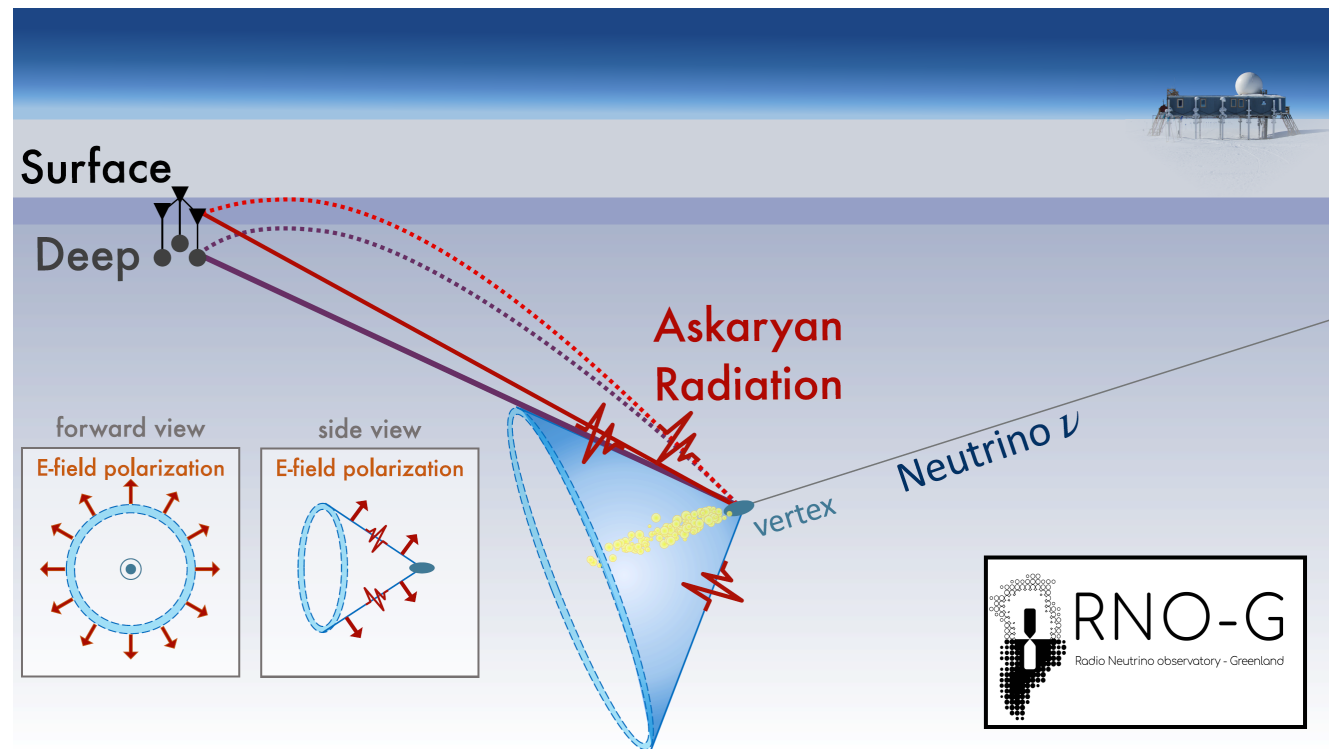
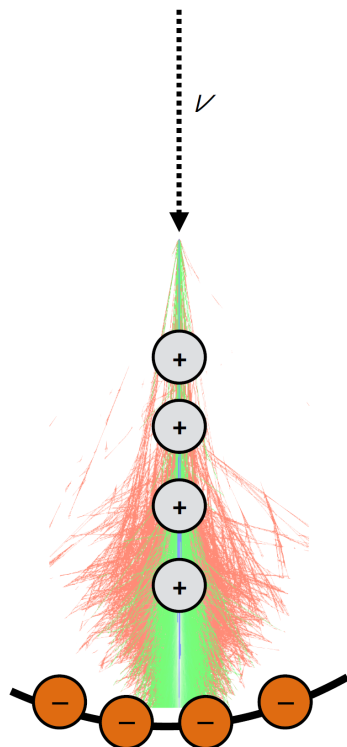
- **Cosmic ν spectrum ? \rightarrow Need more (multi) PeV data**

- **$E_\nu \approx 4\%$ of $E_N \rightarrow$ Search for 10^{18} eV (GZK) neutrinos**

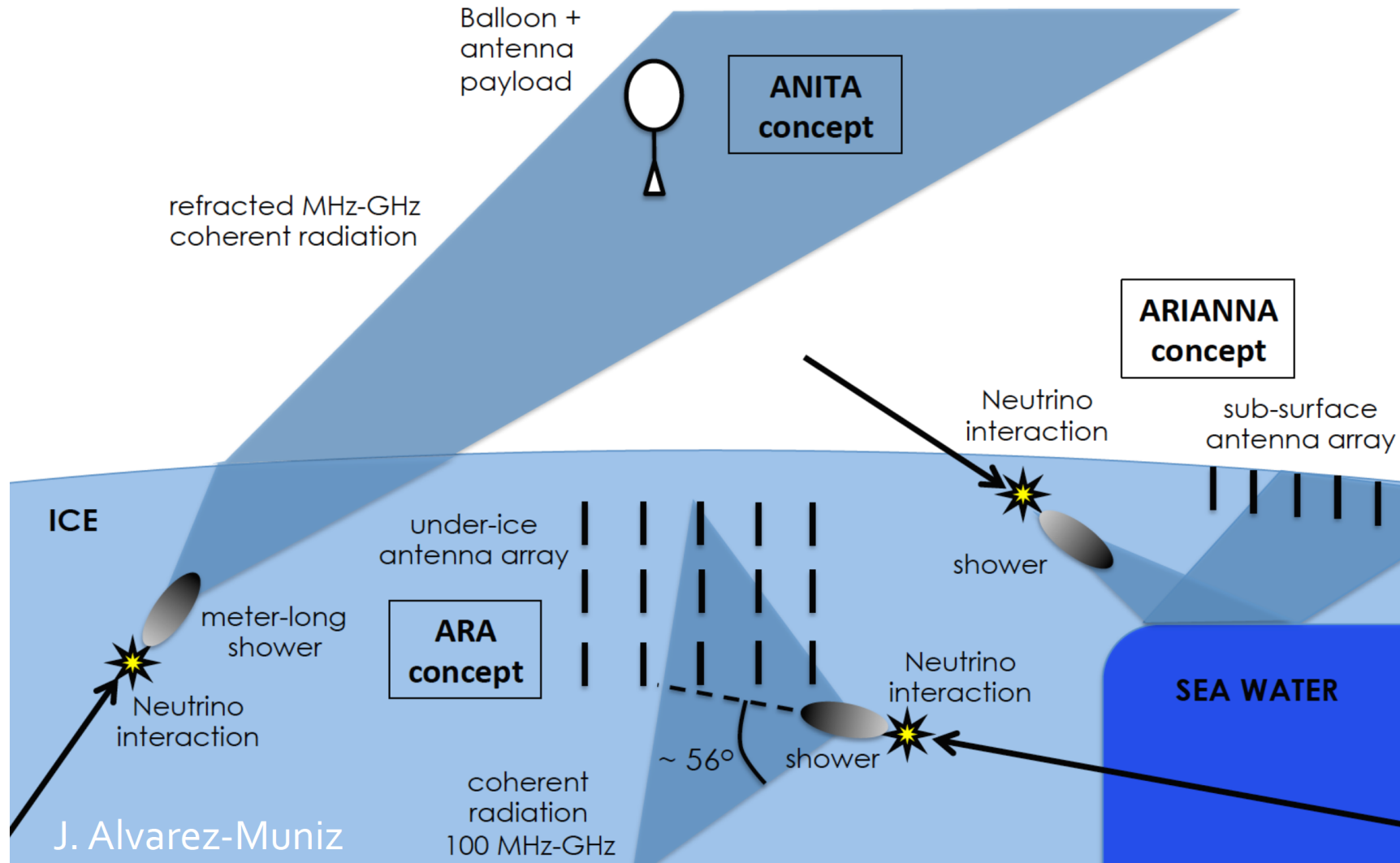
- Current 1 km² IceCube detector is too small for the low >PeV fluxes
 ~5 events ~PeV detected in 10 years → Need >100 times larger detector
 $\lambda_{att} \sim 200\text{m}$ for light → Amount of light sensors and drilling not feasible

Radio signals of ν showers

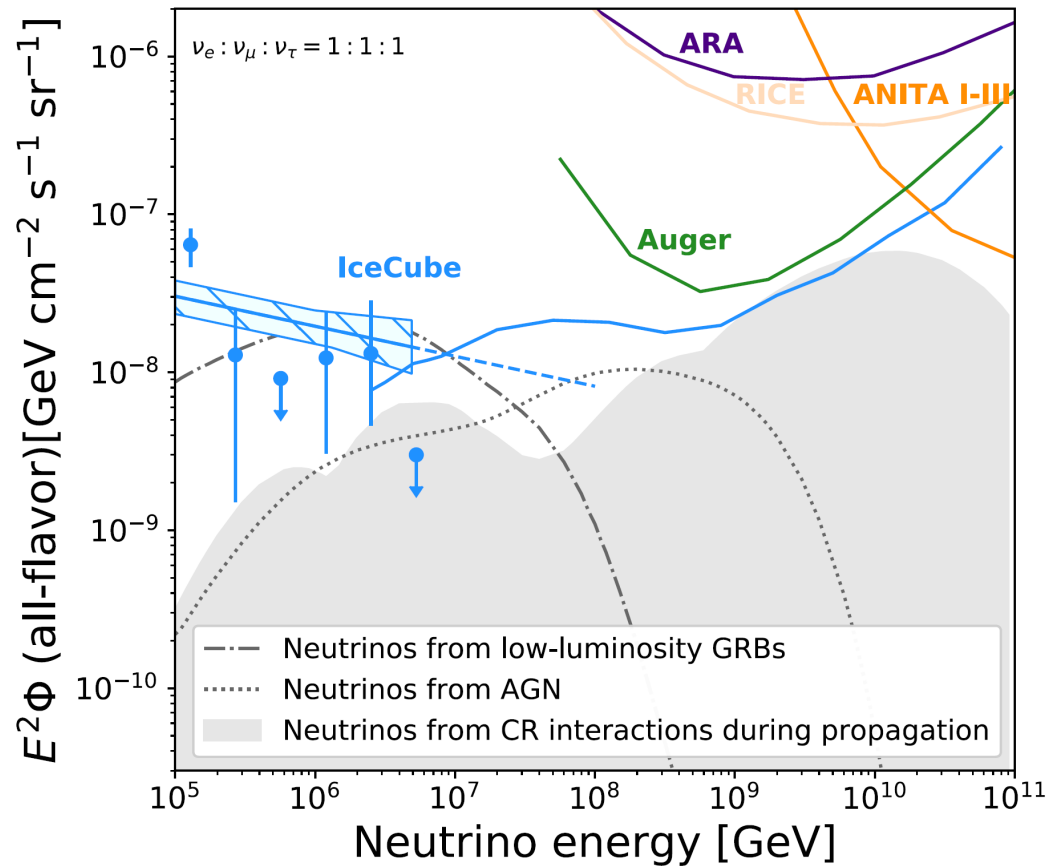
- Long (km-scale) λ_{att} → Cost effective way to cover large (~500 km²) area



Some early projects : 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**

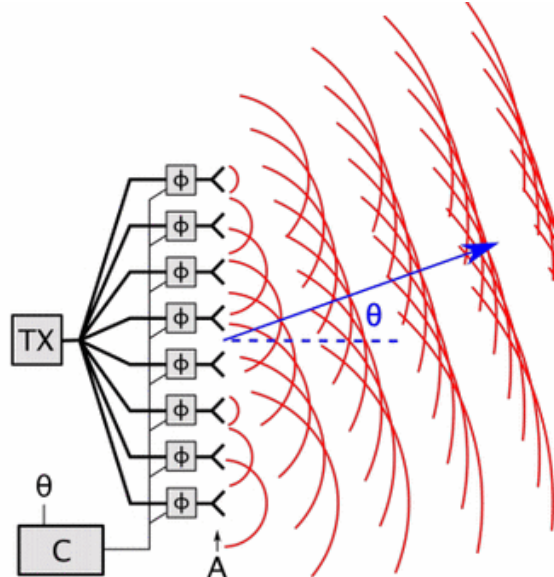
- * **IceCube-Radio energy gap**

Currently not covered

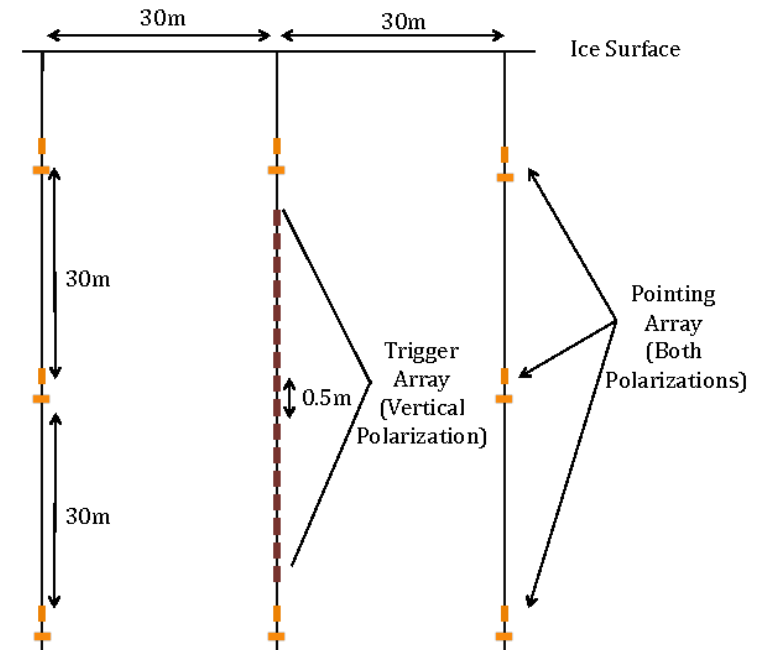
Try to lower the energy threshold

The phased array trigger approach

Well known technique



Testbed implemented in ARA

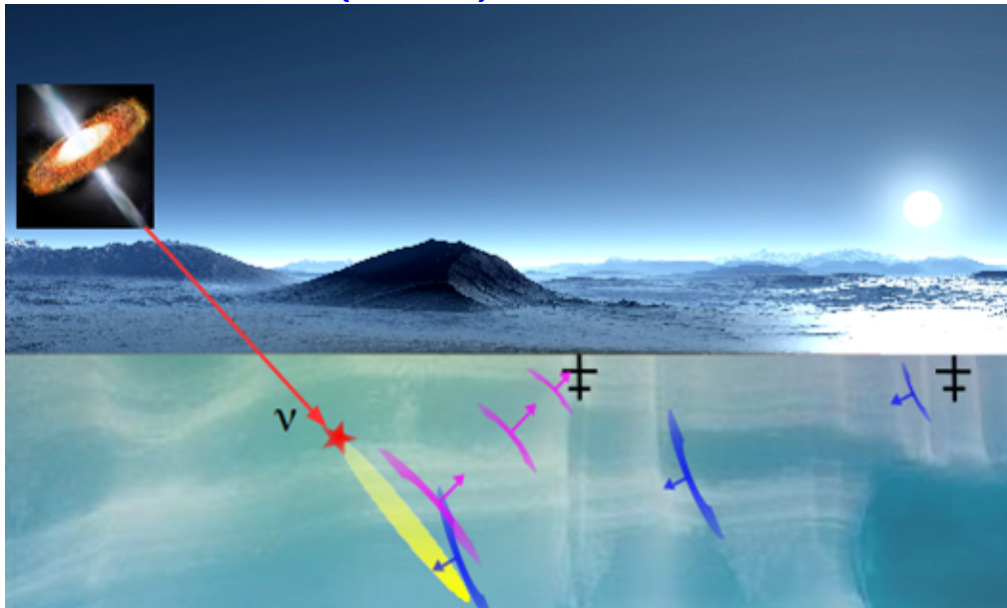


- Similar for receiving signals (e.g. radio astronomy)
- Using multiple beams → Directional sensitivity

- 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

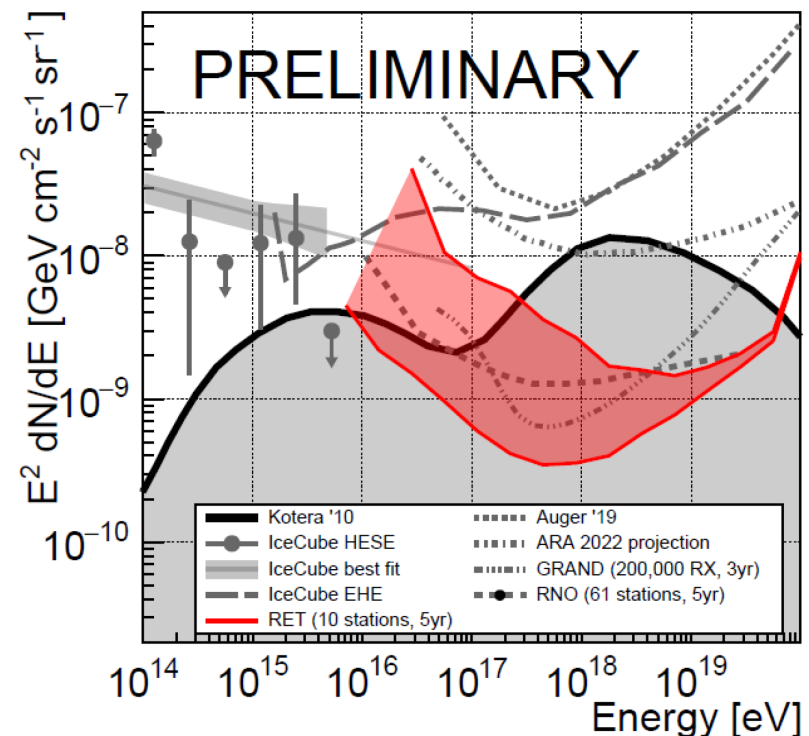


[Credit Krijn de Vries]

- Signal scales with transmit power
→ Allows low energy threshold
- Beam tests confirmed the principle
(PRL 124 (2020) 091101)

Simulation results

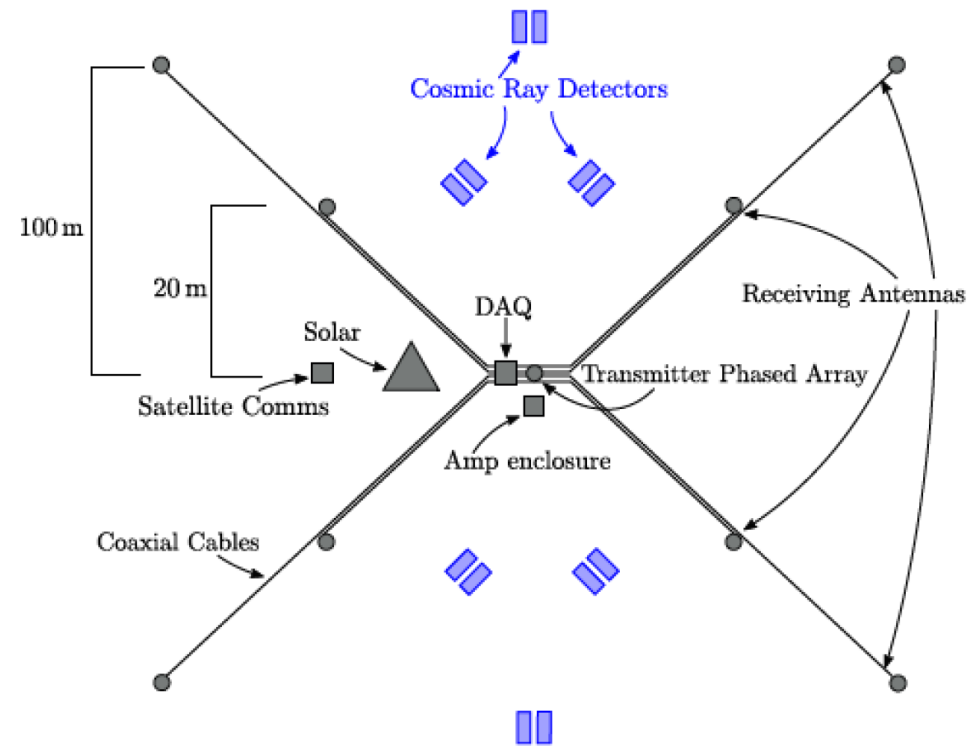
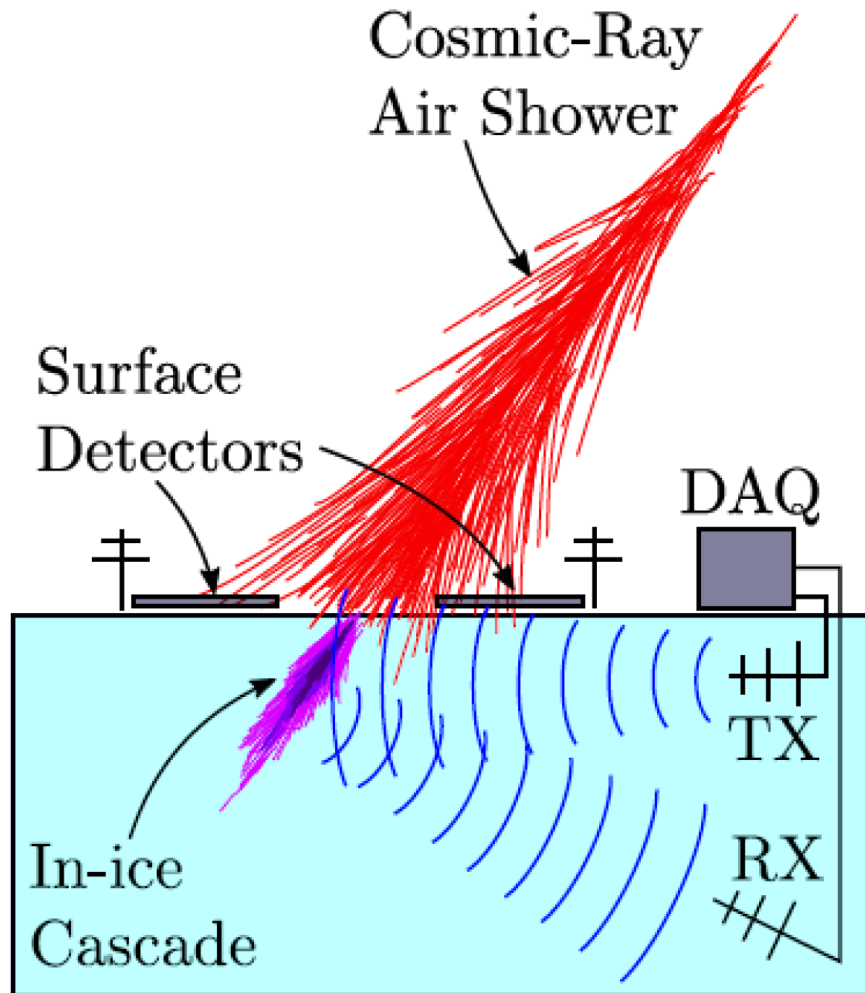
ICRC2021 proceedings



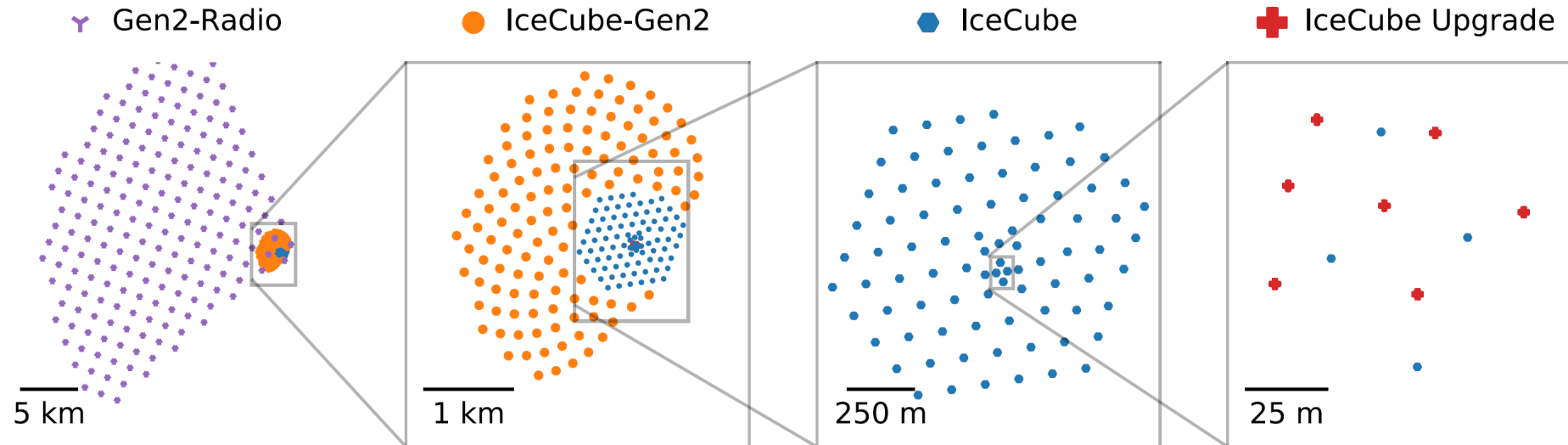
Fills the IceCube-Radio E gap

→ Possibility for full energy coverage

Towards an in-situ proof of principle at Taylor Dome Antarctica
(ArXiv:2104.00459)



The IceCube-Gen2 extended neutrino observatory



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

The RNO-G radio array

- **Participating institutes**

VUB, ULB, UGent, UChicago, PSU, OSU, UW-Madison, DESY, KU, MSU, Alabama, Uppsala, Erlangen

- **IIHE plays a leading role**

Project fully funded by FWO-IRI

- **Location: Summit station Greenland**

→ Inverted seasons w.r.t. SP

No interference with IC Upgrade

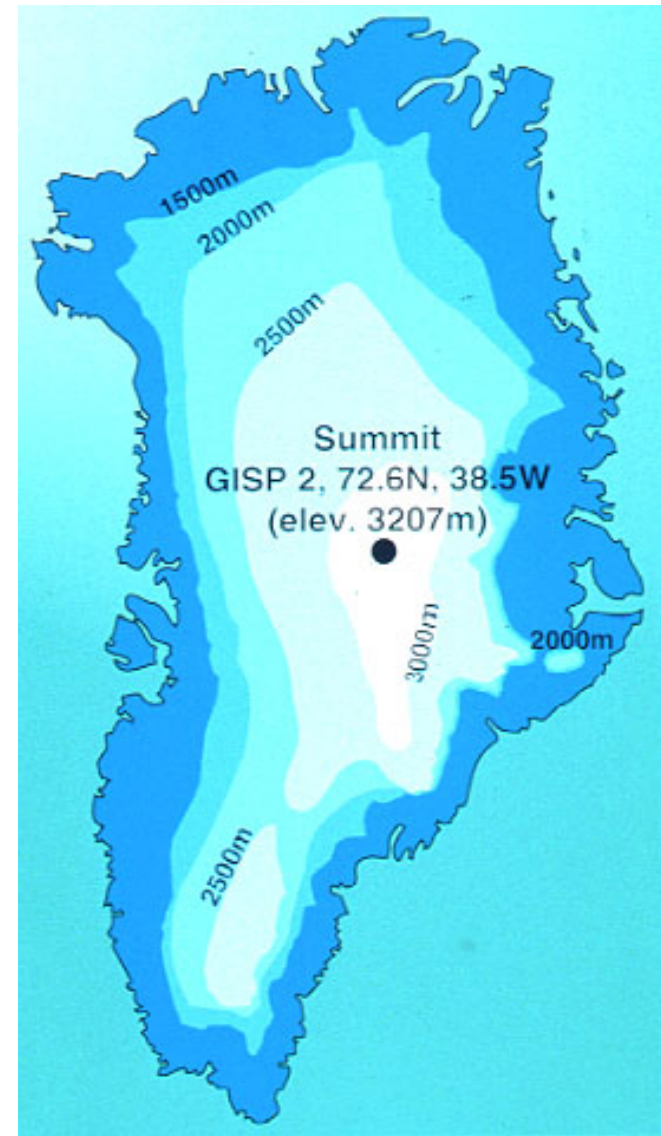
Same NSF cargo planes etc. available

- **35 autonomous stations in 2024**

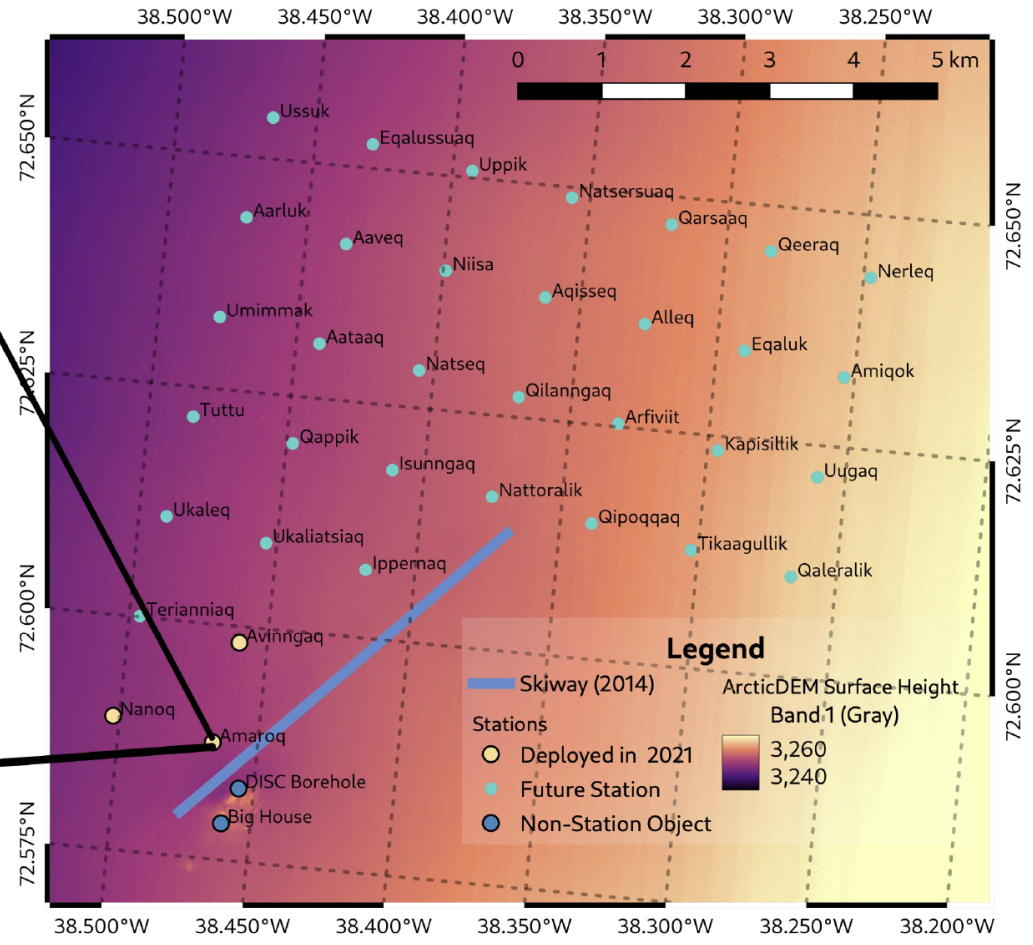
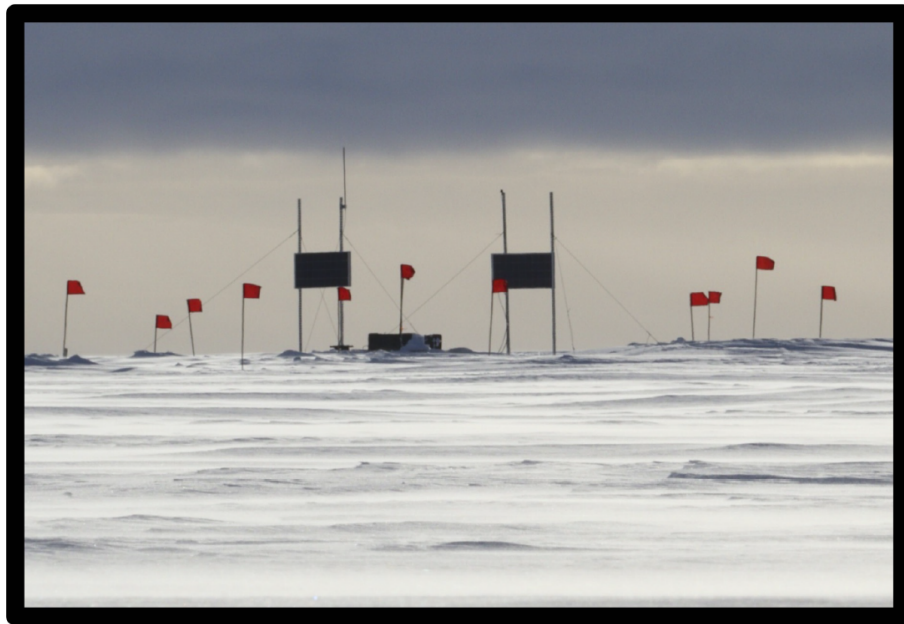
→ $\sim 50 \text{ km}^2$ array

1st deployment in 2021 (3 stations)

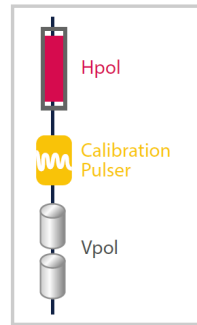
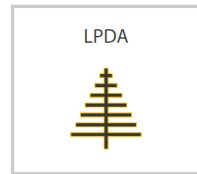
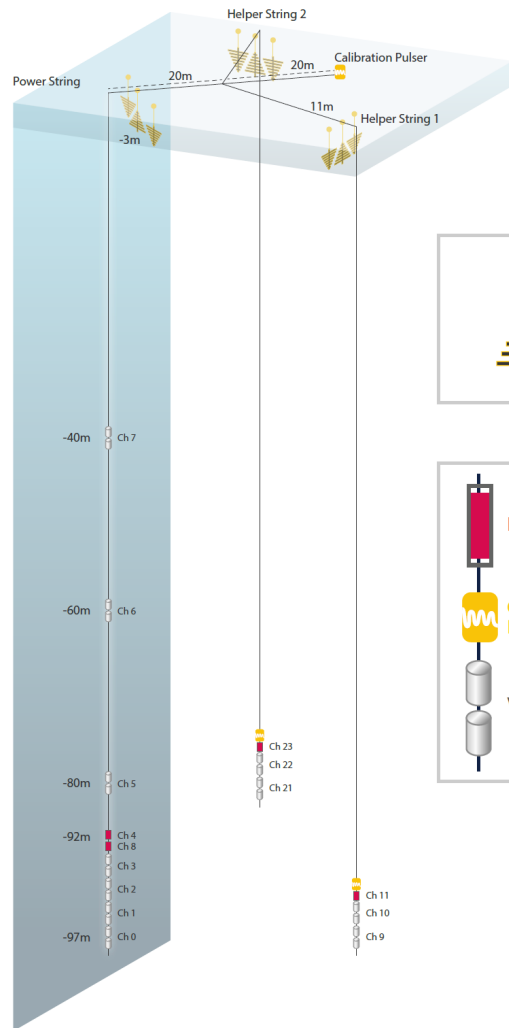
→ **Already > 3x size of IceCube**



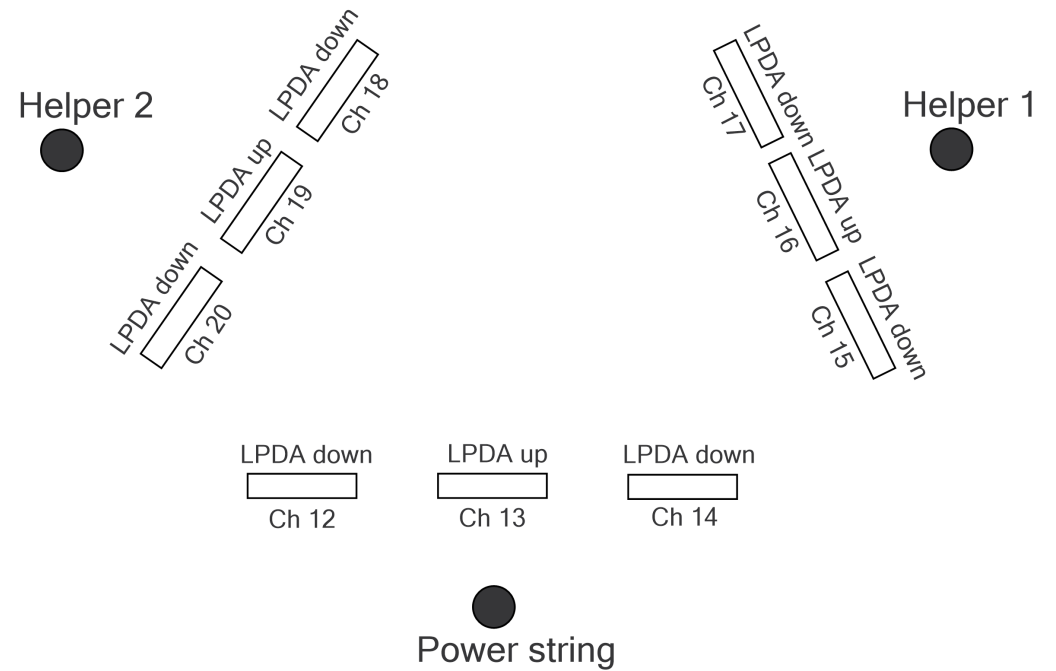
Array geometry



RNO-G Station layout (JINST 16 (2021) P03025)

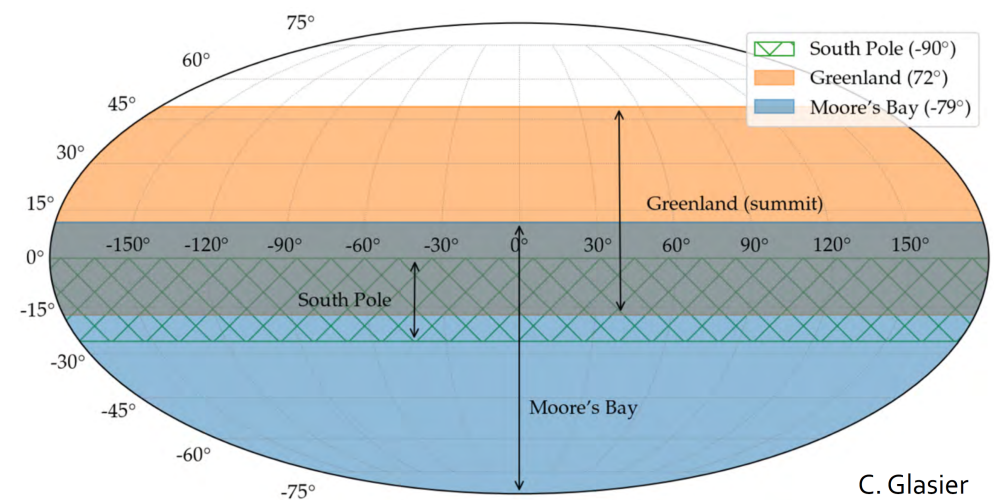
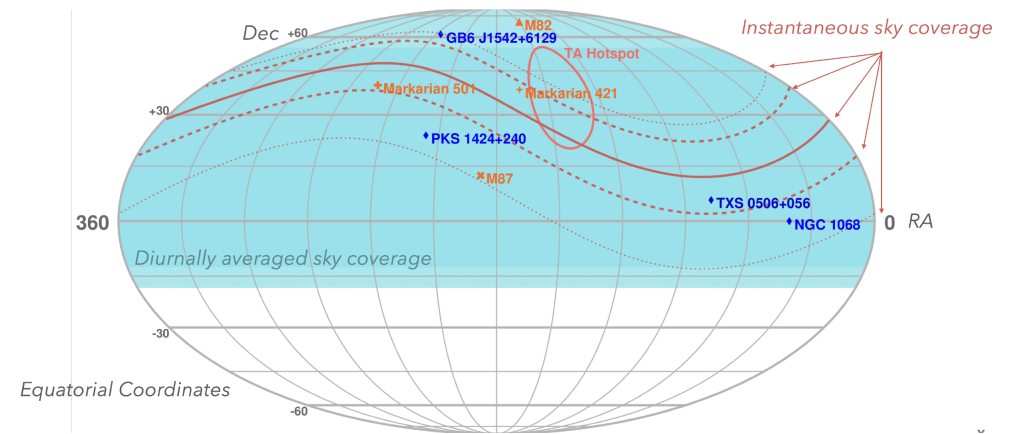


RNO-G Channel Mapping Top View



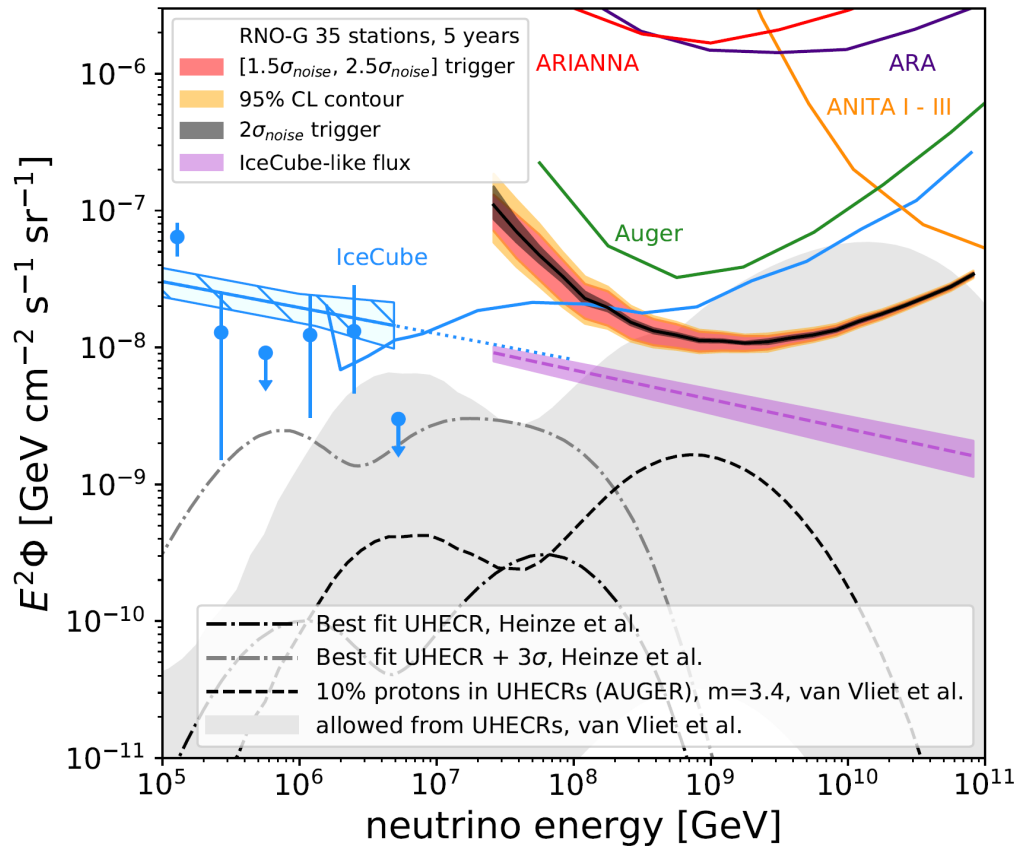
Strong science case

- **Overlapping FoV with IC optical**
Same location seen at PeV and TeV
→ **Steady sources studies**
- **Complementary FoV to SP radio**
Earth rotation: Larger sky coverage
→ **Detection of transients**
- **Join the MM alert system**
- **Develop a real time alert system**
Focus of the IIHE team



(Equatorial Coordinates)

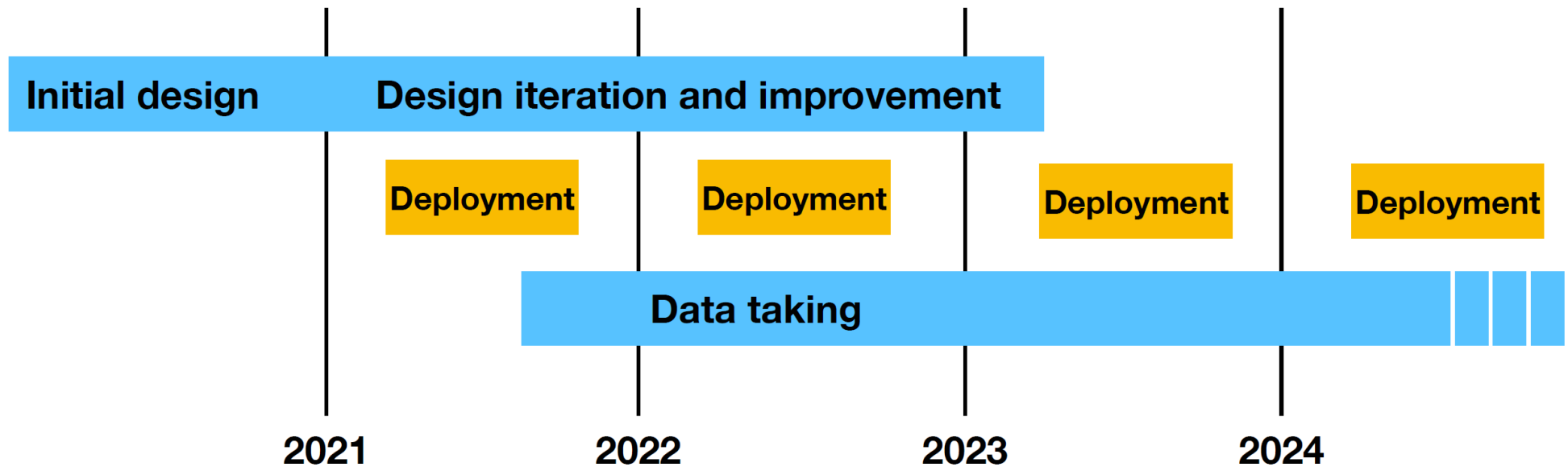
Sensitivity



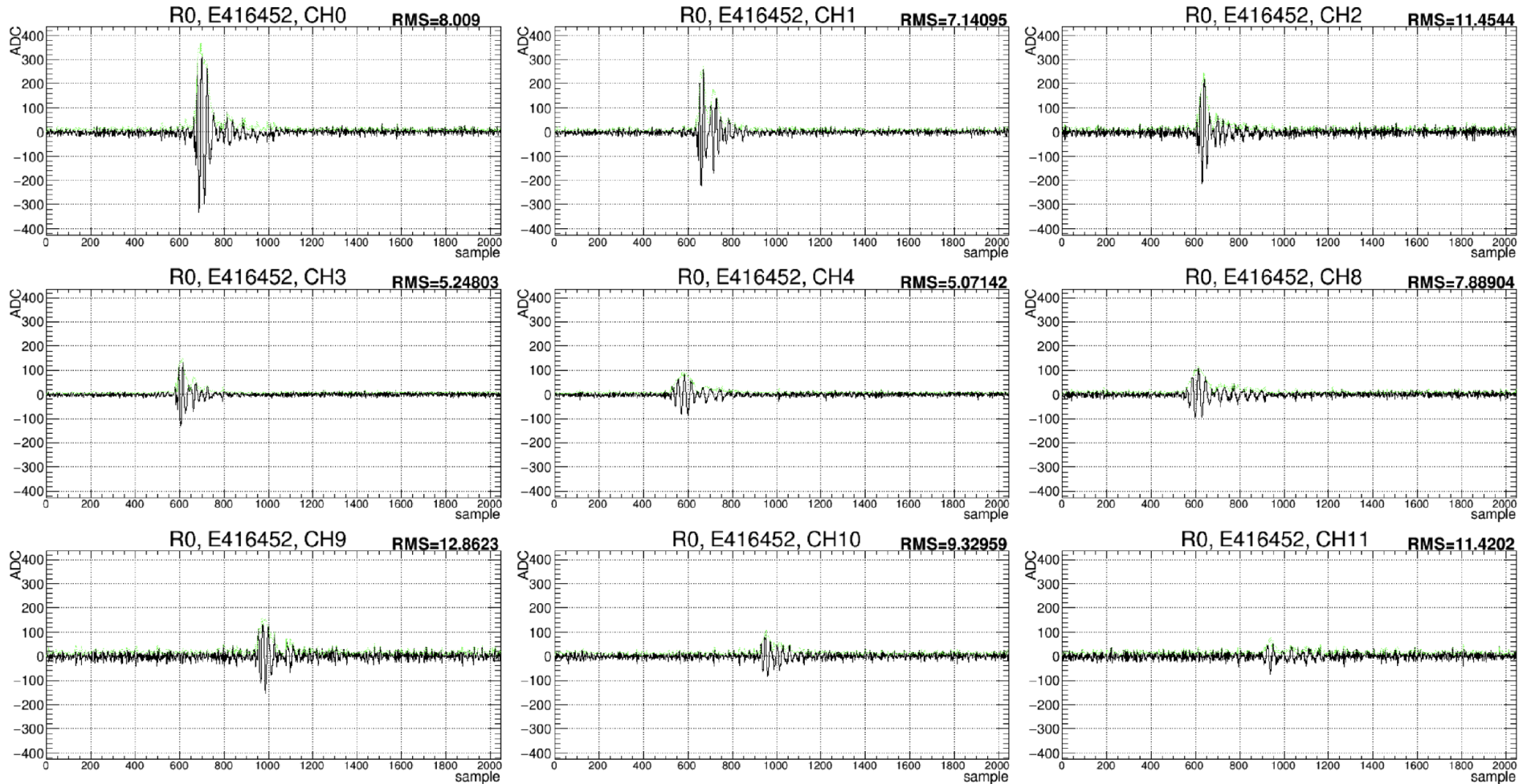
A real discovery experiment

- First real exploration of GZK regime
 - Uncover UHE sources c.q. transients
 - Gen2-radio $\sim 10x$ more sensitive
 - Lowering the threshold
- Improve the IceCube optical data

The Covid-19 corrected RNO-G timeline

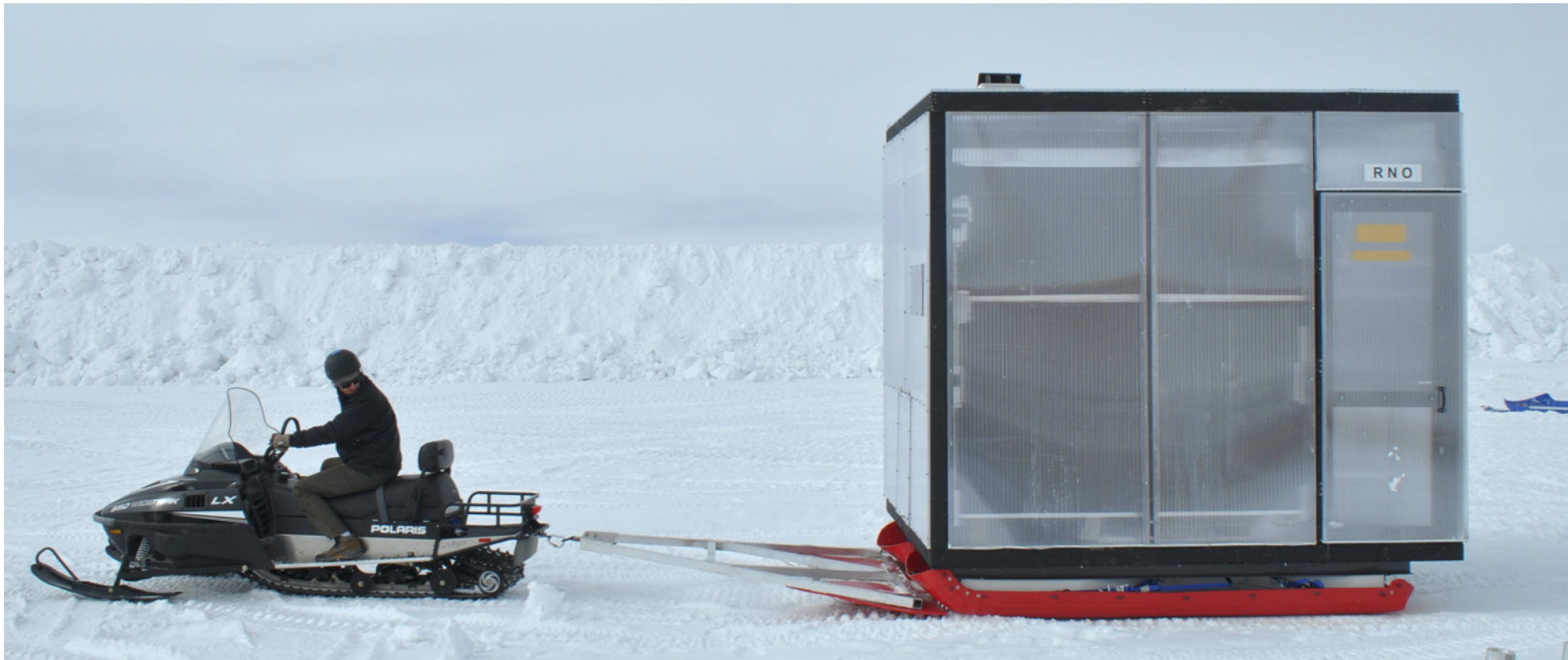


After switching on the first station ...

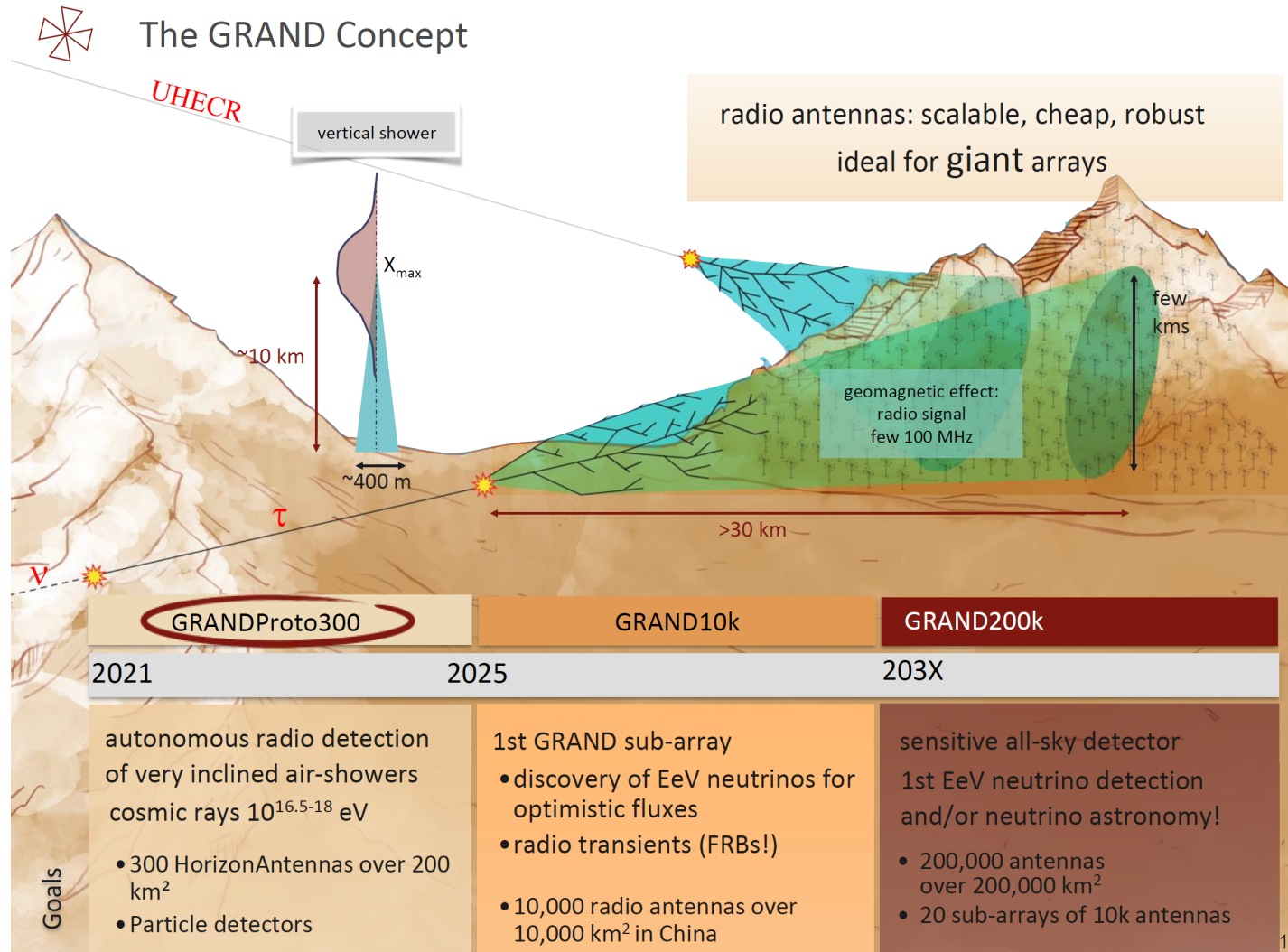


Are we that lucky to see already a neutrino ?

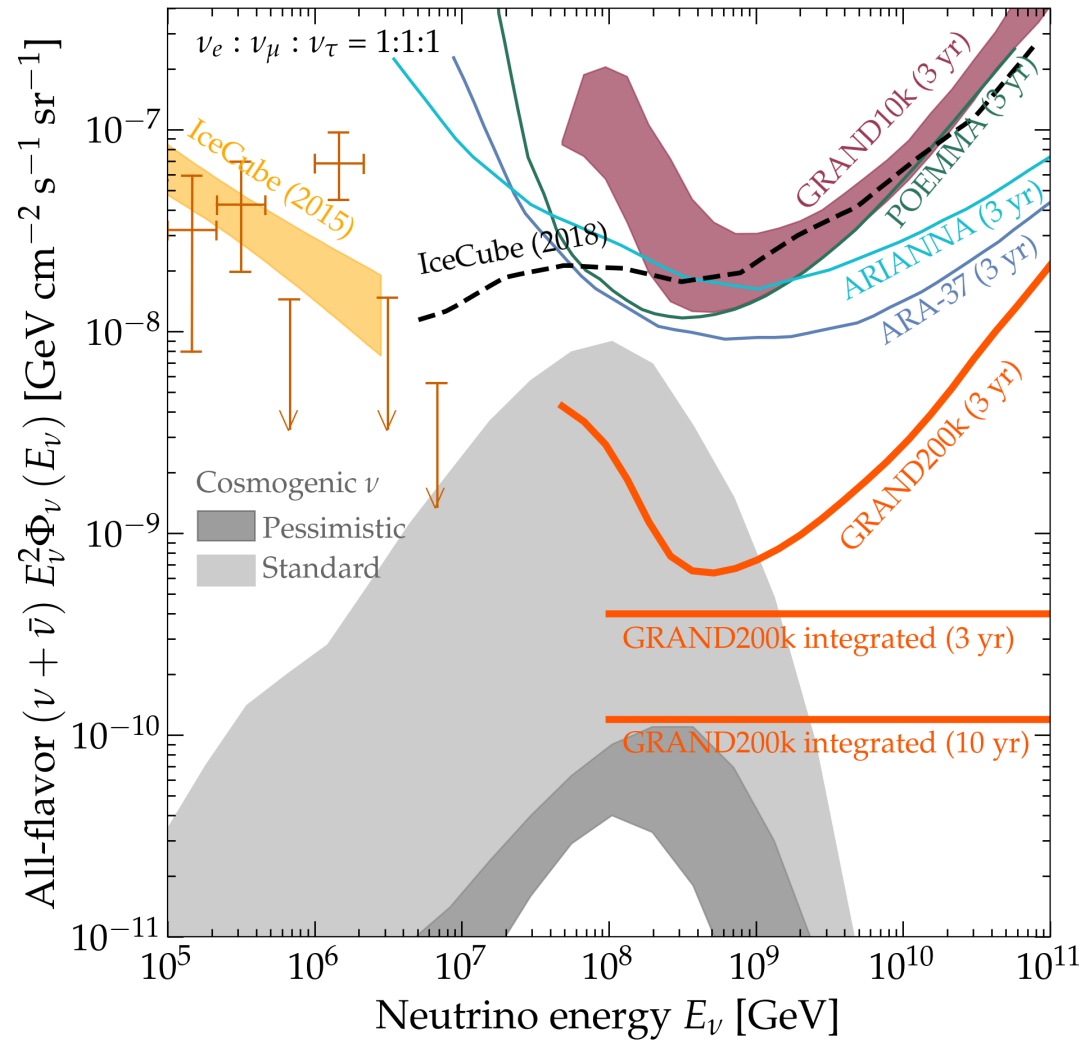
Our signal ...



Detection principle of UHE ν_τ



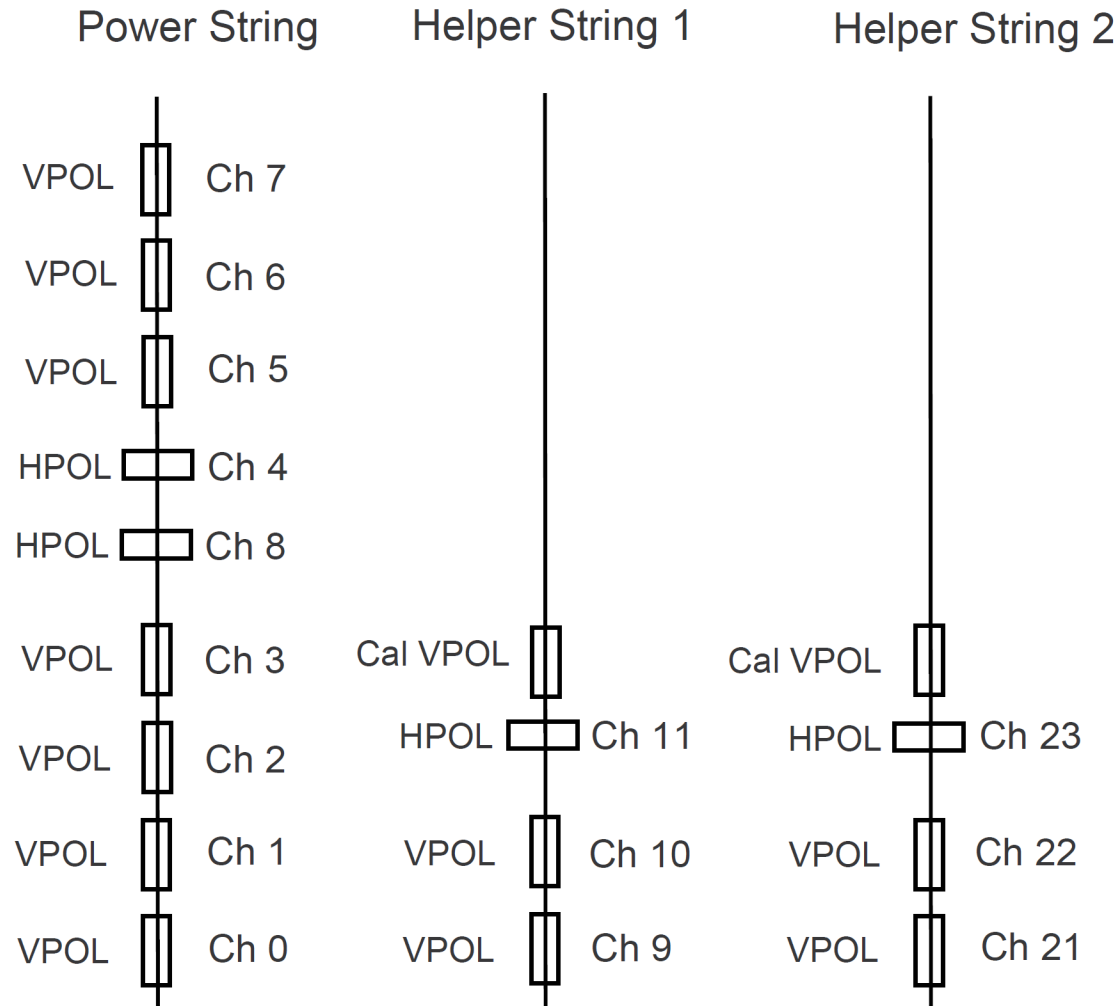
GRAND sensitivity



- **Need for more statistics of cosmic ν at $>PeV$ energies**
 - Study spectral characteristics of high-energy cosmic ν
 - Investigate/confirm the GZK effect and UHE ν from sources/transients
- **Need for >100 times the current IceCube size**
 - **Only feasible with detection via radio signals** ($\lambda_{att} \sim 1$ km)
 - Radio component of ~ 500 km² planned for IceCube-Gen2
- **Deployment has started for a ~ 50 km² radio array in Greenland (RNO-G)**
 - Test technical aspects (low threshold, autonomous operation, scalability)
 - First physics exploration of unknown energy regime (GZK neutrinos)
IIHE has taken a lead in the RNO-G project (5M FWO-IRI grant)
 - First deployment of 3 stations in 2021 \rightarrow 35 stations in 2024
Development of radar reflection technique (2M ERC-StG of Krijn)
- **IIHE people involved** : Katie, Rose, Simona, Paramita, Kumiko, Marine, Pragati, Vesna, Dieder, Enrique, Juanan, Krijn, Olaf, Simon, Stijn, Uzair, Jethro, Tim, Jörg, Godwin, Hershhal and Nick

Backup Slides

RNO-G Channel Mapping Side View



The RNO-G DAQ system

3 GHz sampling 8-bit ADC Two 2048 sample buffers → ~ 600 ns windows

