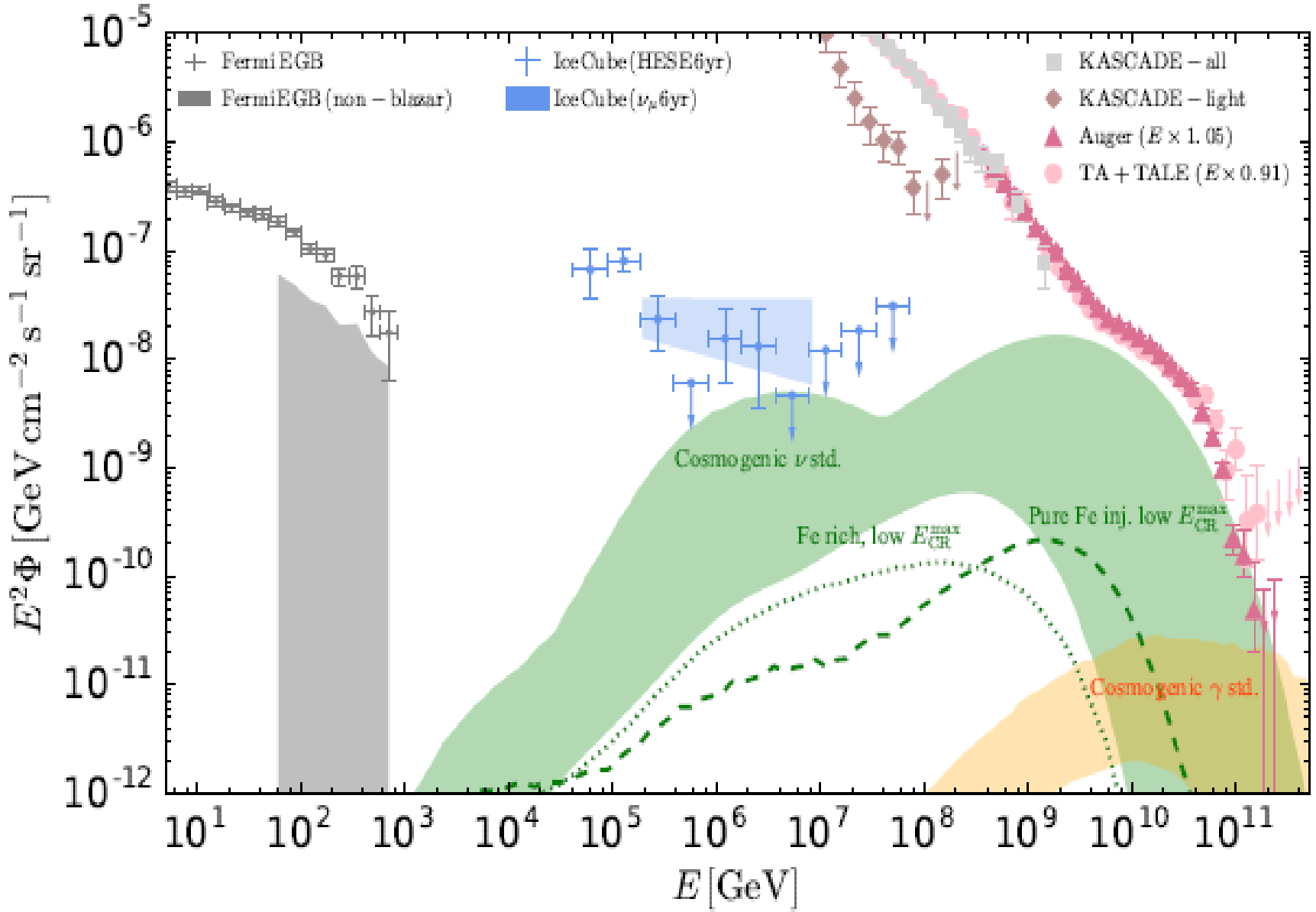
(French contributions to) the GRAND project

Olivier Martineau-Huynh

Atelier PNHE, 15 setembre 2021

Why UHE neutrinos?



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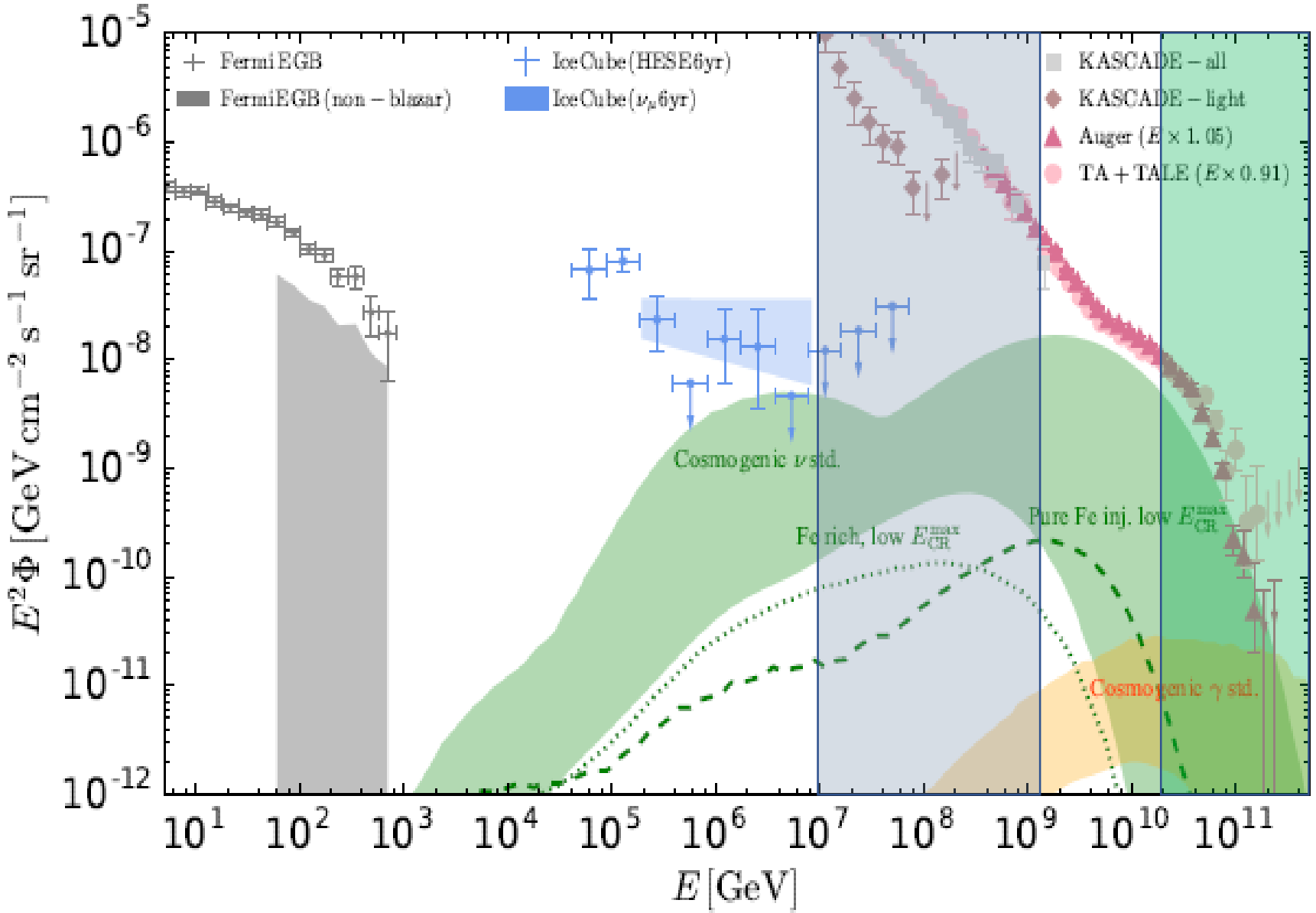

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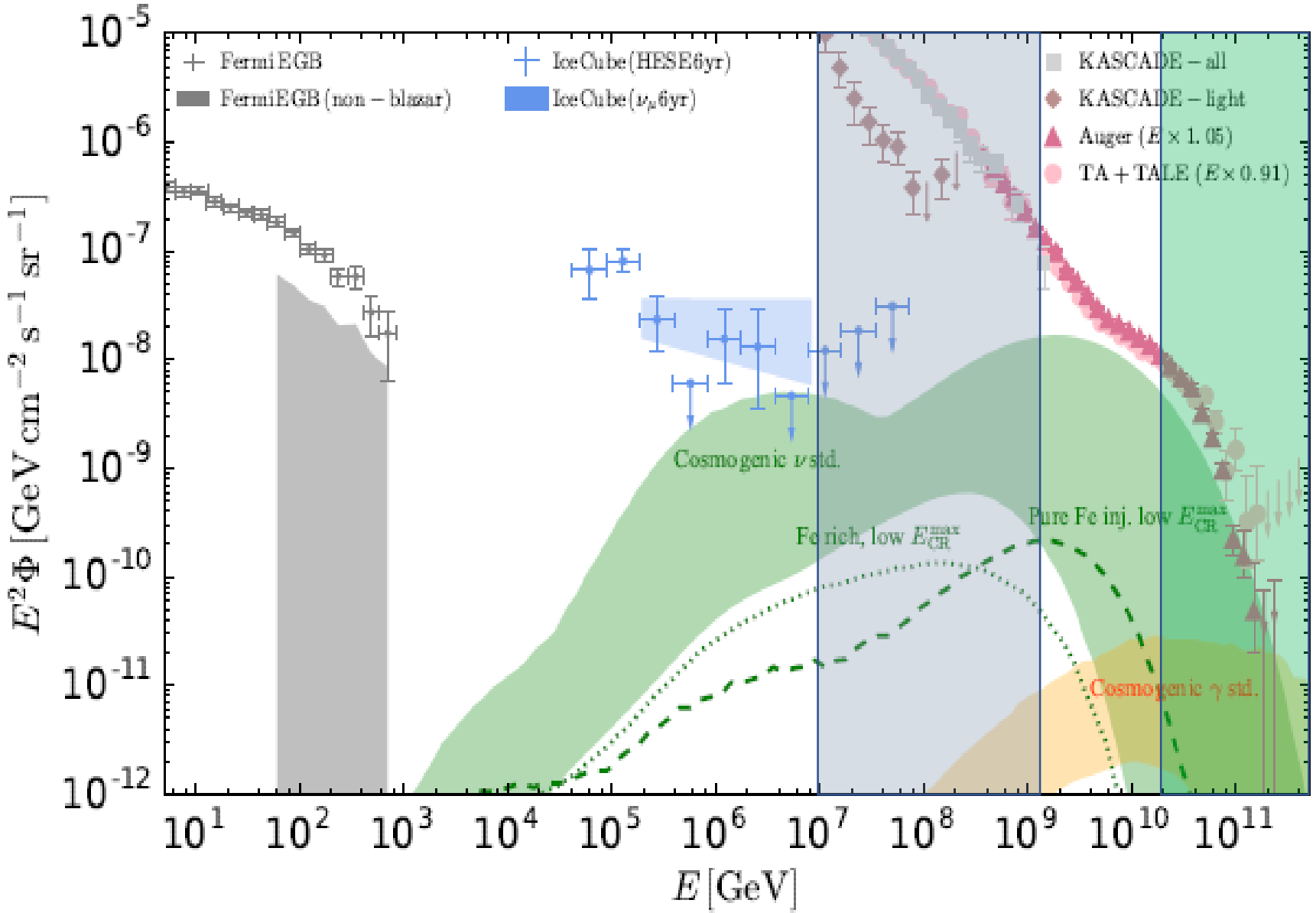

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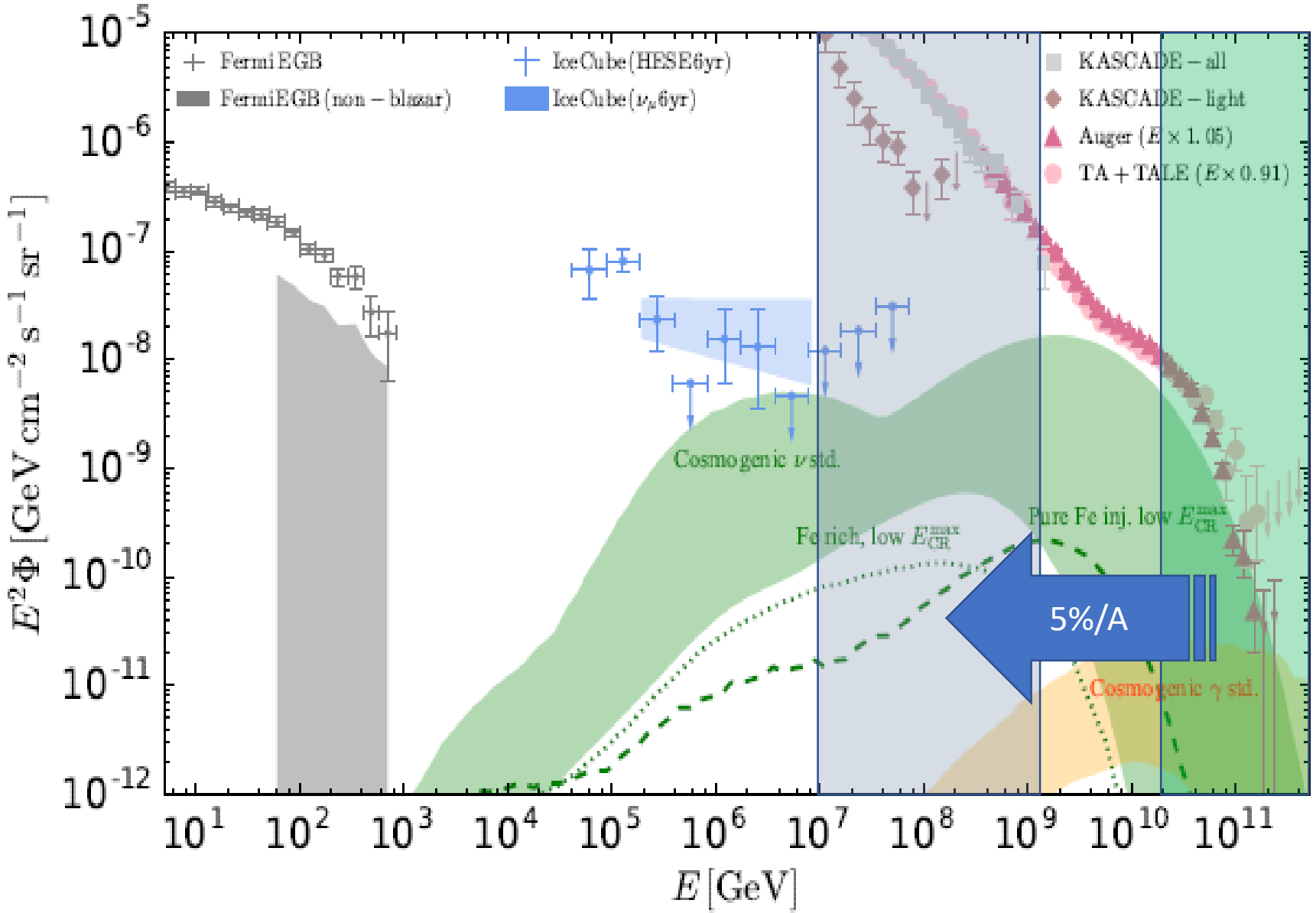

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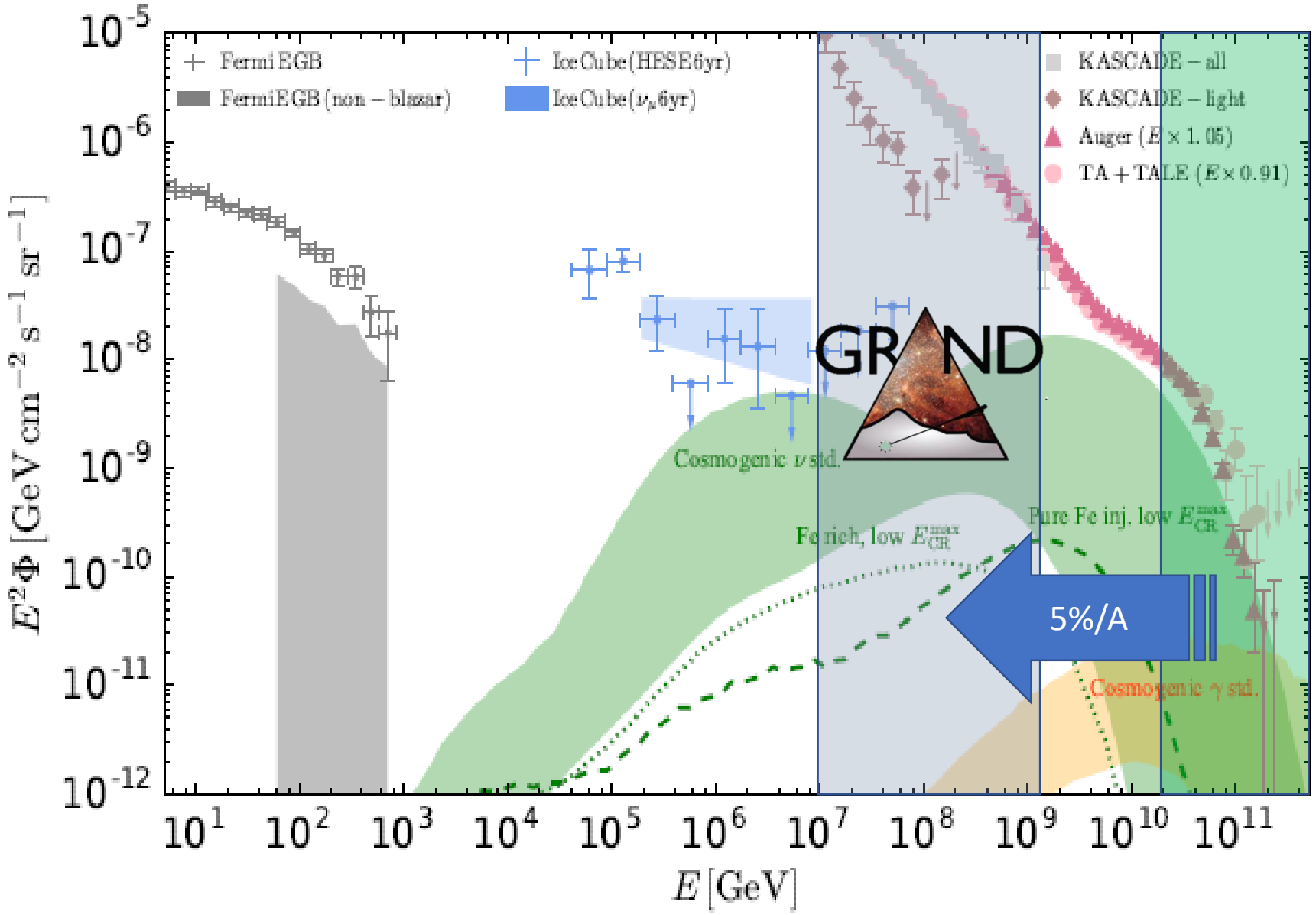
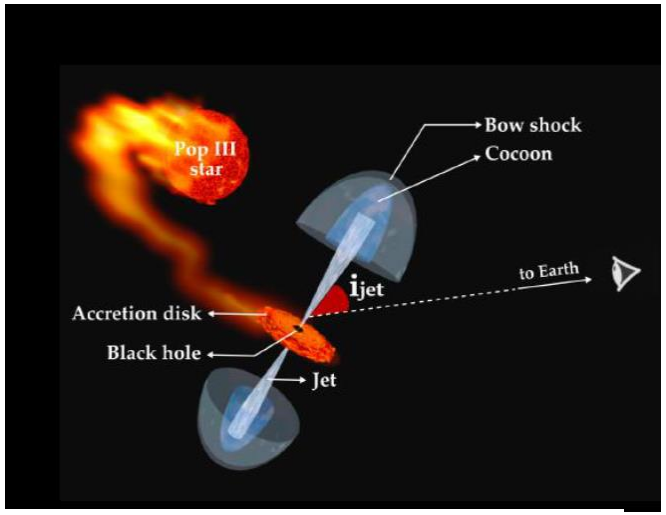
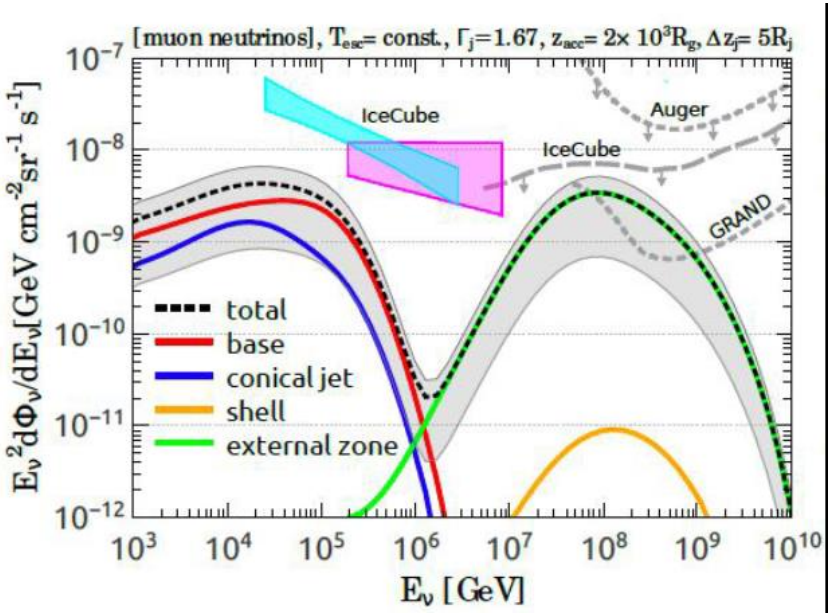


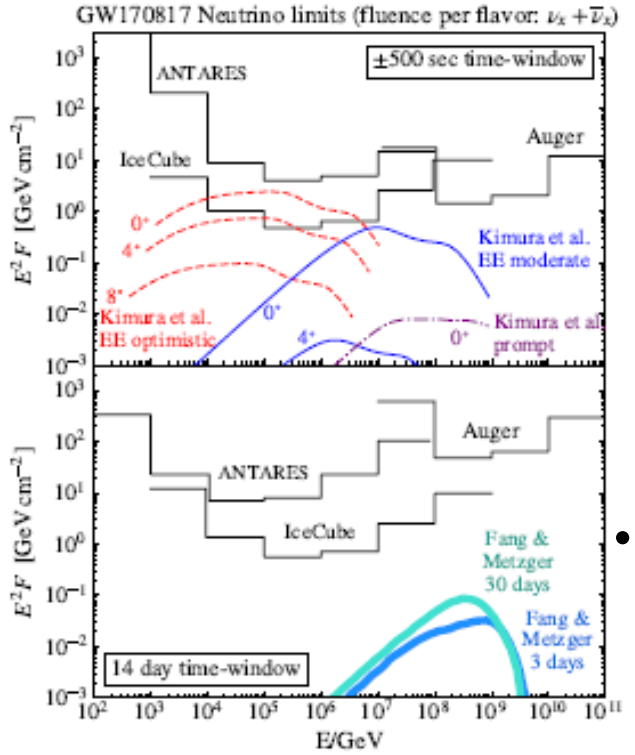
Science case for UHE neutrinos





- Direct probe for UHE cosmic sources

Carulli et al., arXiv:2101.02999

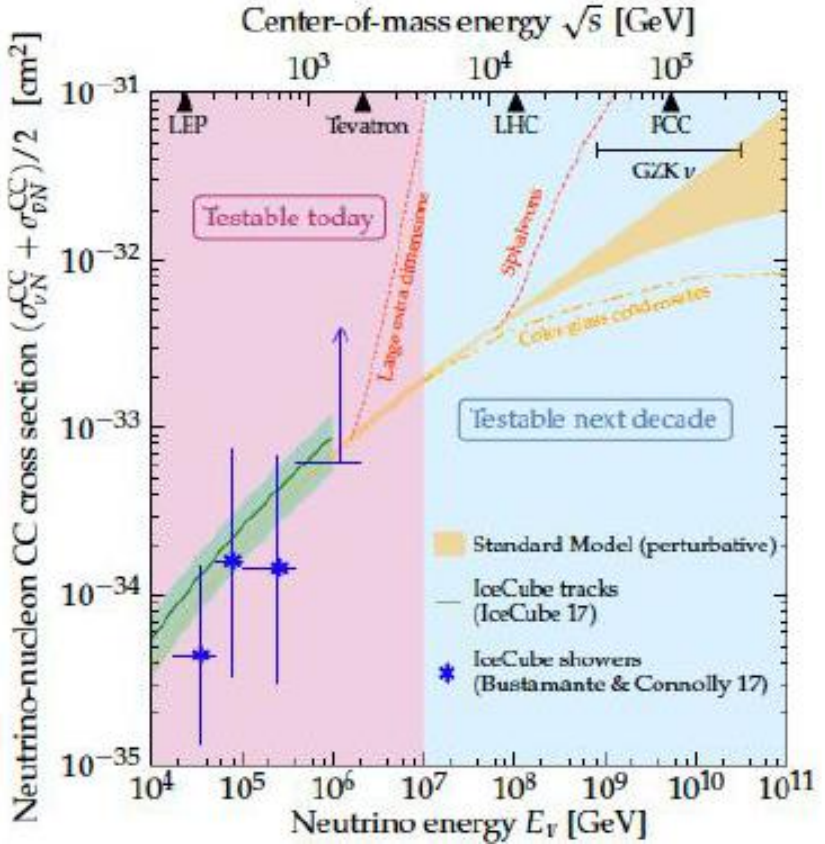


- Muli-messenger / transient astronomy

Albert et al., arXiv:1710.05839.

- Probe for fundamental physics (cross section, flavor, LIV (?))

Bustamante and Connolly, arXiv:1711.11043.



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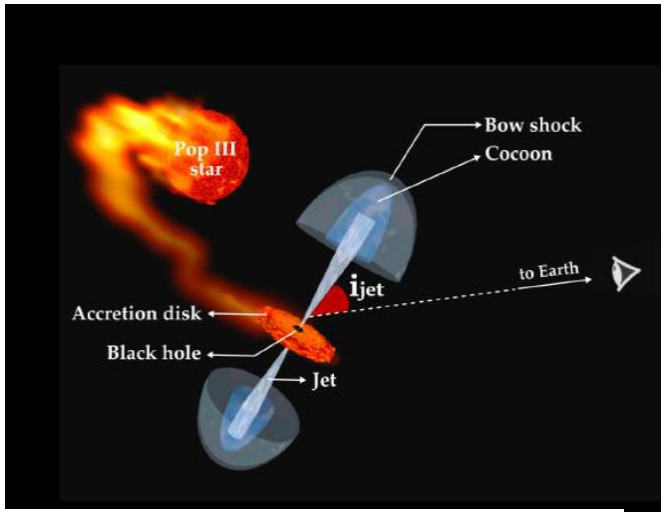

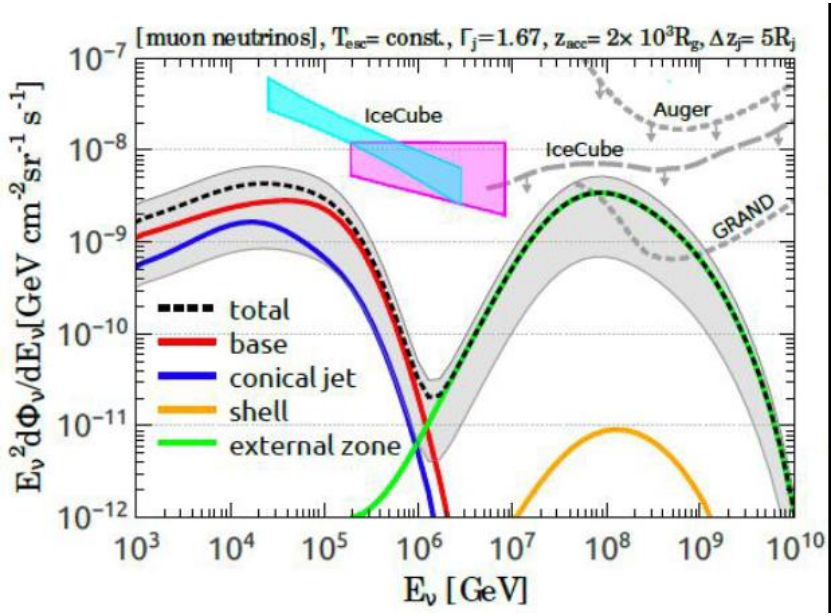

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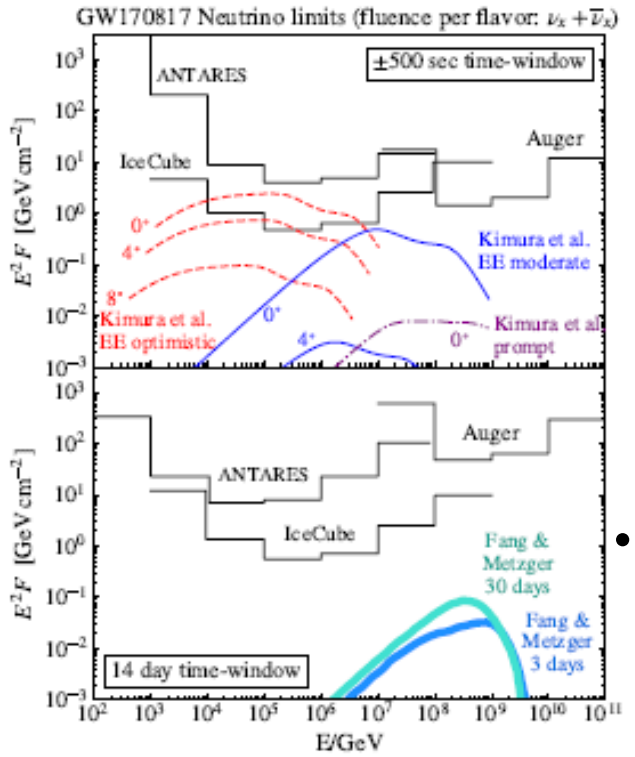

- Muli-messenger / transient astronomy

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Key parameters:

- **Sensitivity**
- **Angular resolution**
- **Field of view**
- **(Energy resolution)**

- Probe for fundamental physics (cross section, flavor, LIV (?))

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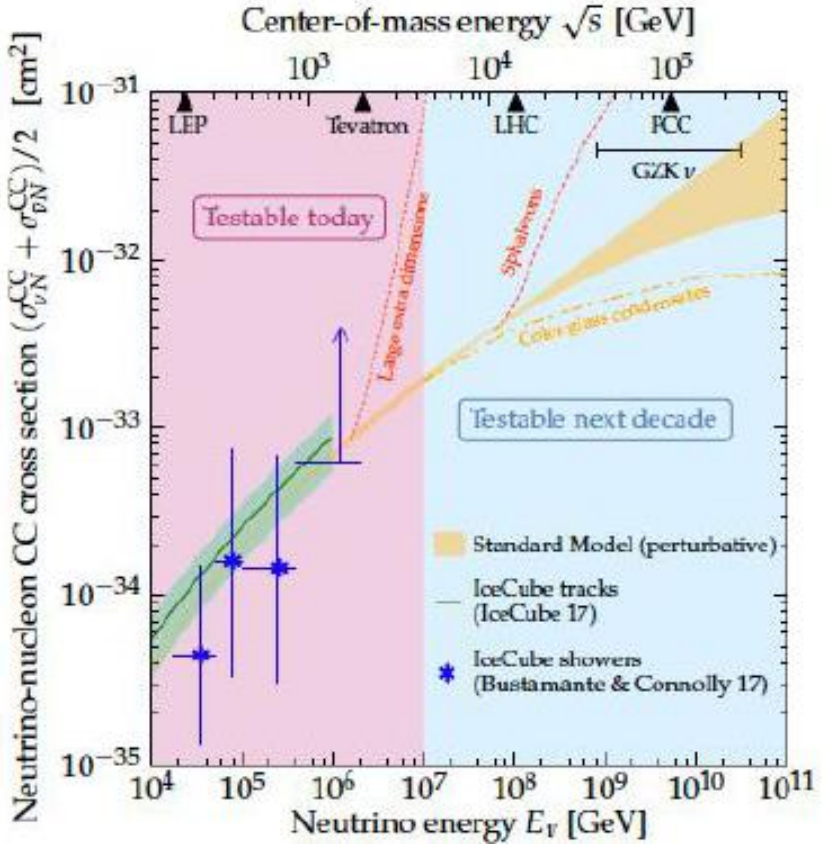
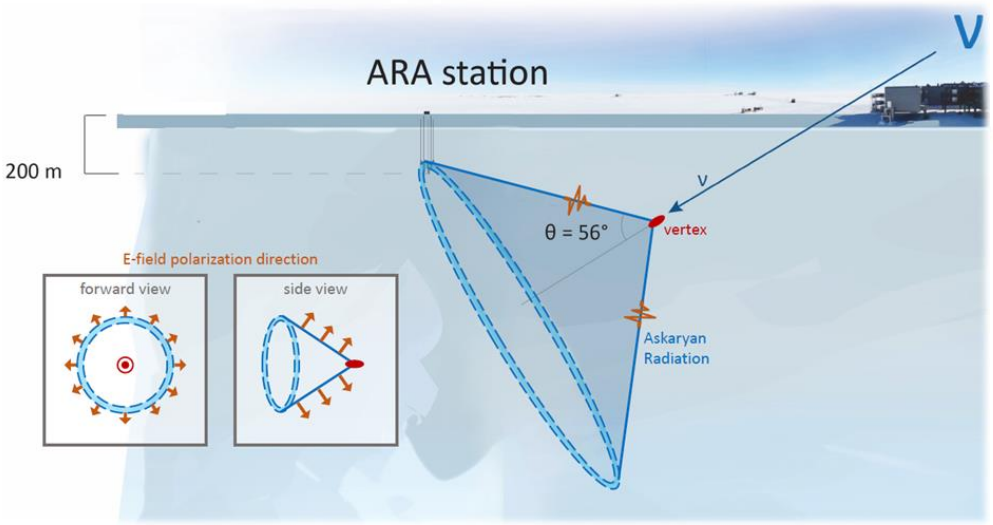
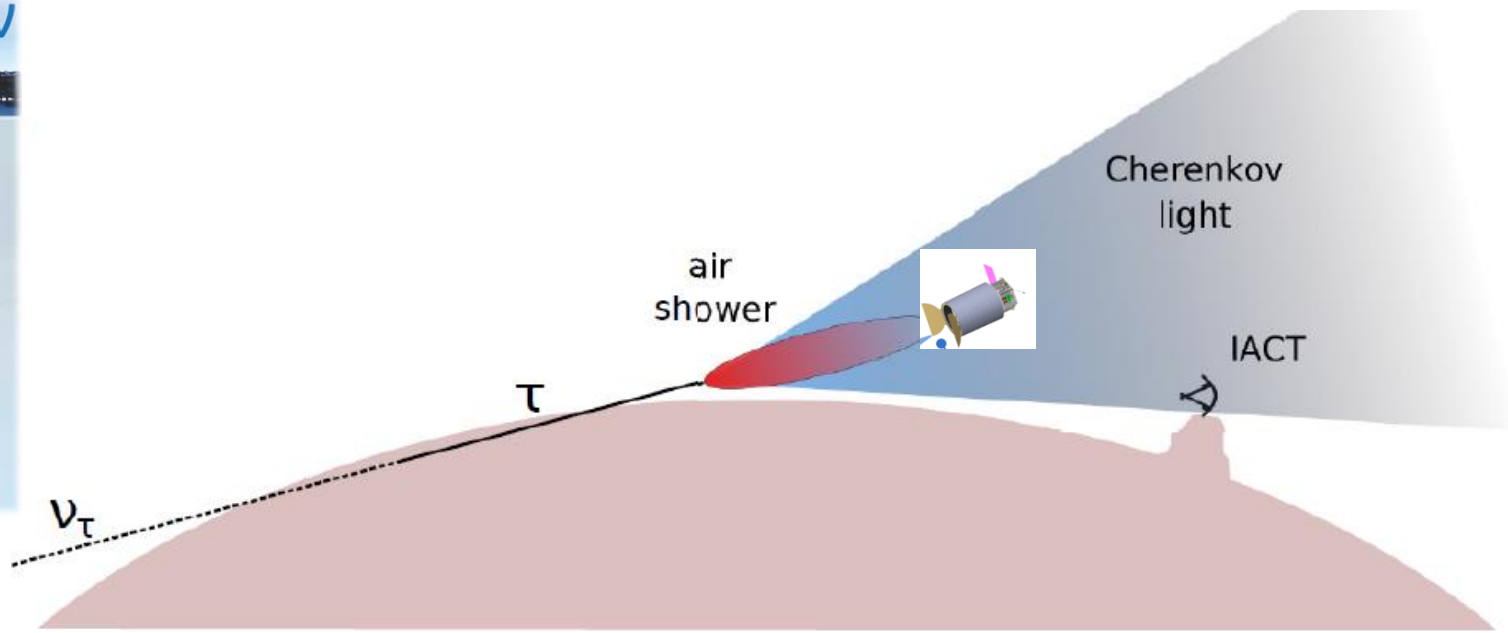


Detection of UHE neutrinos

- **Low fluxes ➔ giant detection volume (10^3s km3)**
- Prospective work following various strategies
  - In-ice radio detection (IceCube-Gen2, RNO-G, etc…)
  - Cerenkov/Fluorescence of neutrino-induced air shower detection (POEMMA, TRINITY)
  - **Radio detection of neutrino-induced air showers (GRAND)**

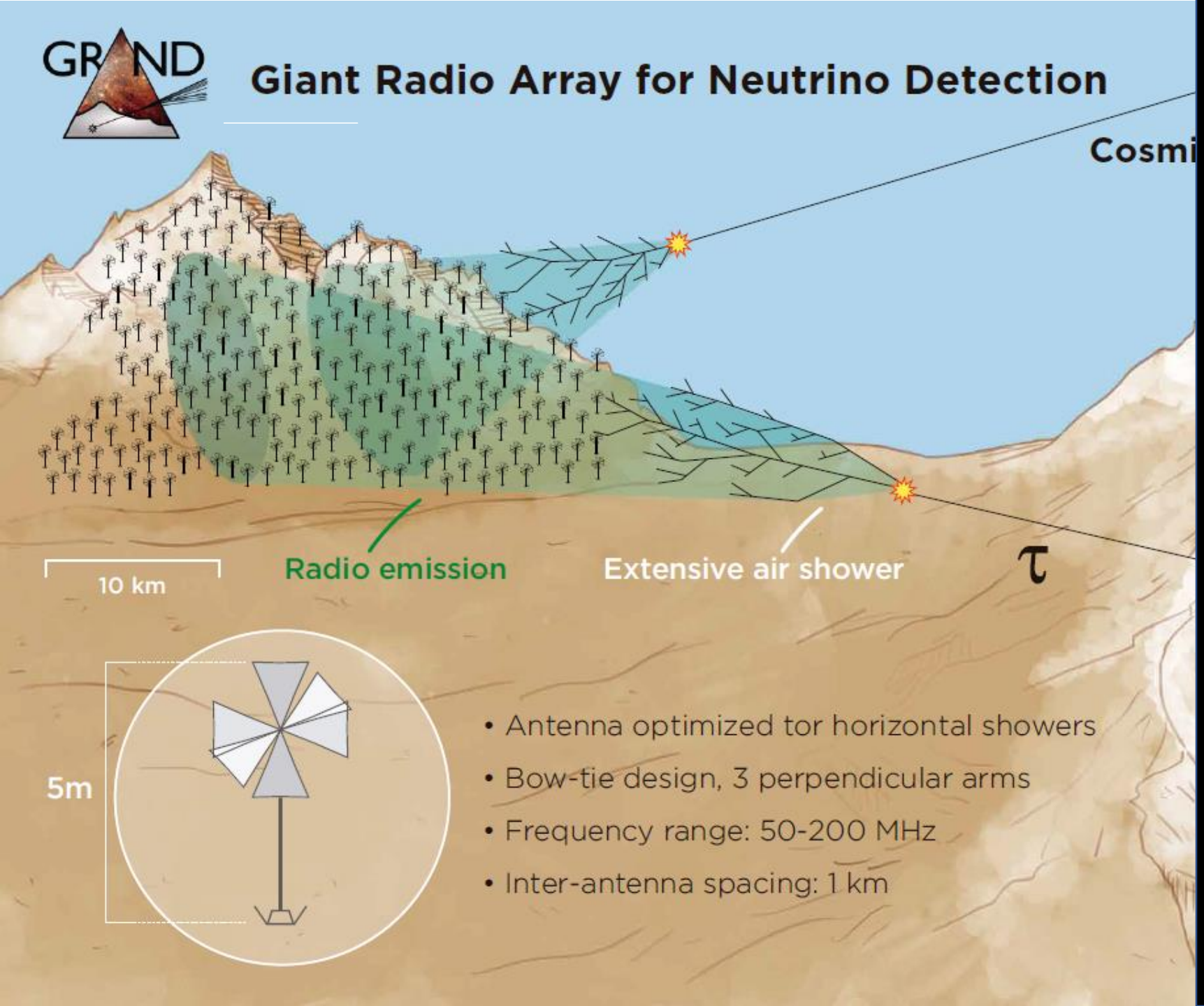


Abbasi et al., arXiv:2011.03545

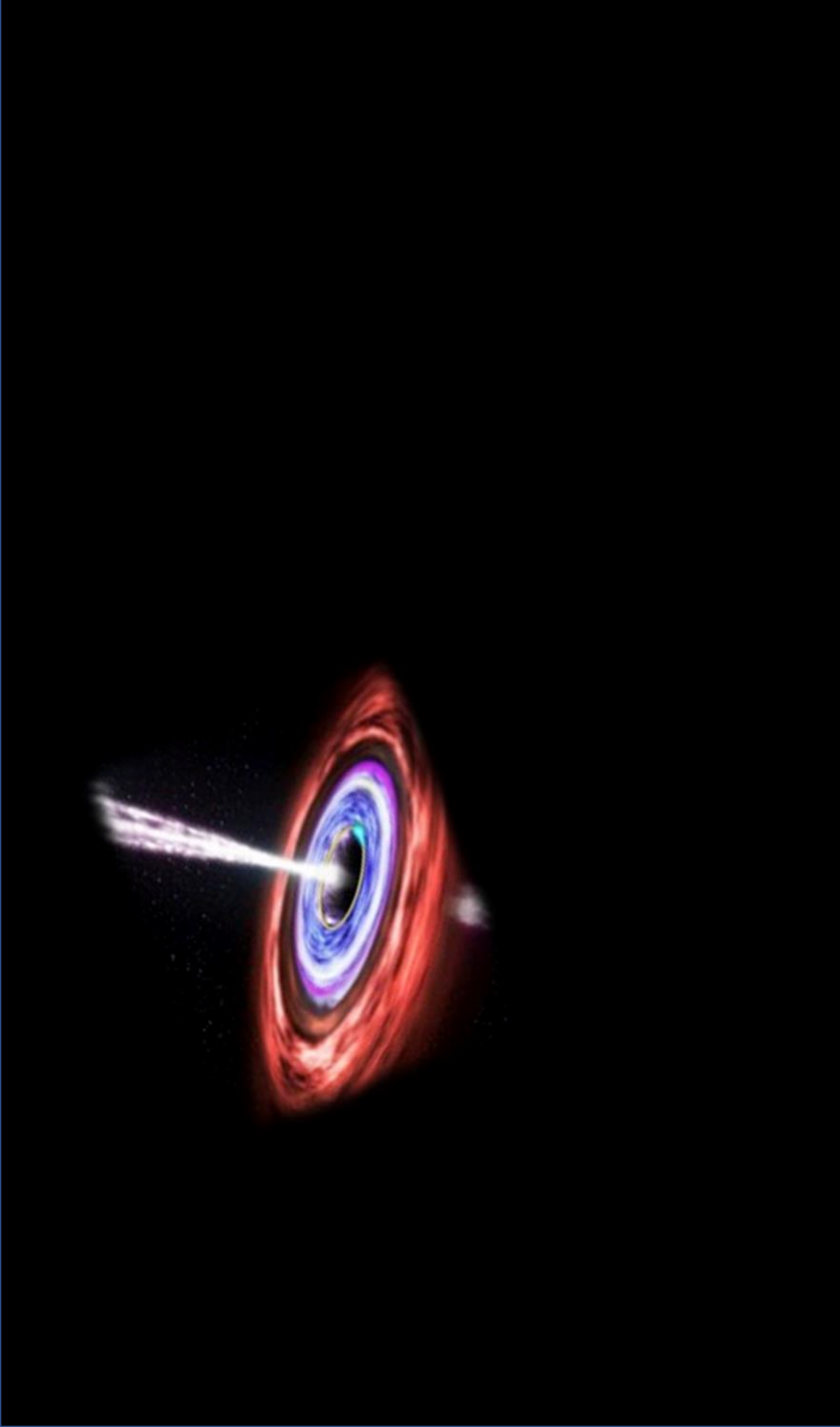


Adapted from N. Otte, ICRC2019

Giant Radio Array for Neutrino Detection



- Antenna optimized tor horizontal showers
- Bow-tie design, 3 perpendicular arms
- Frequency range: 50-200 MHz
- Inter-antenna spacing: 1 km



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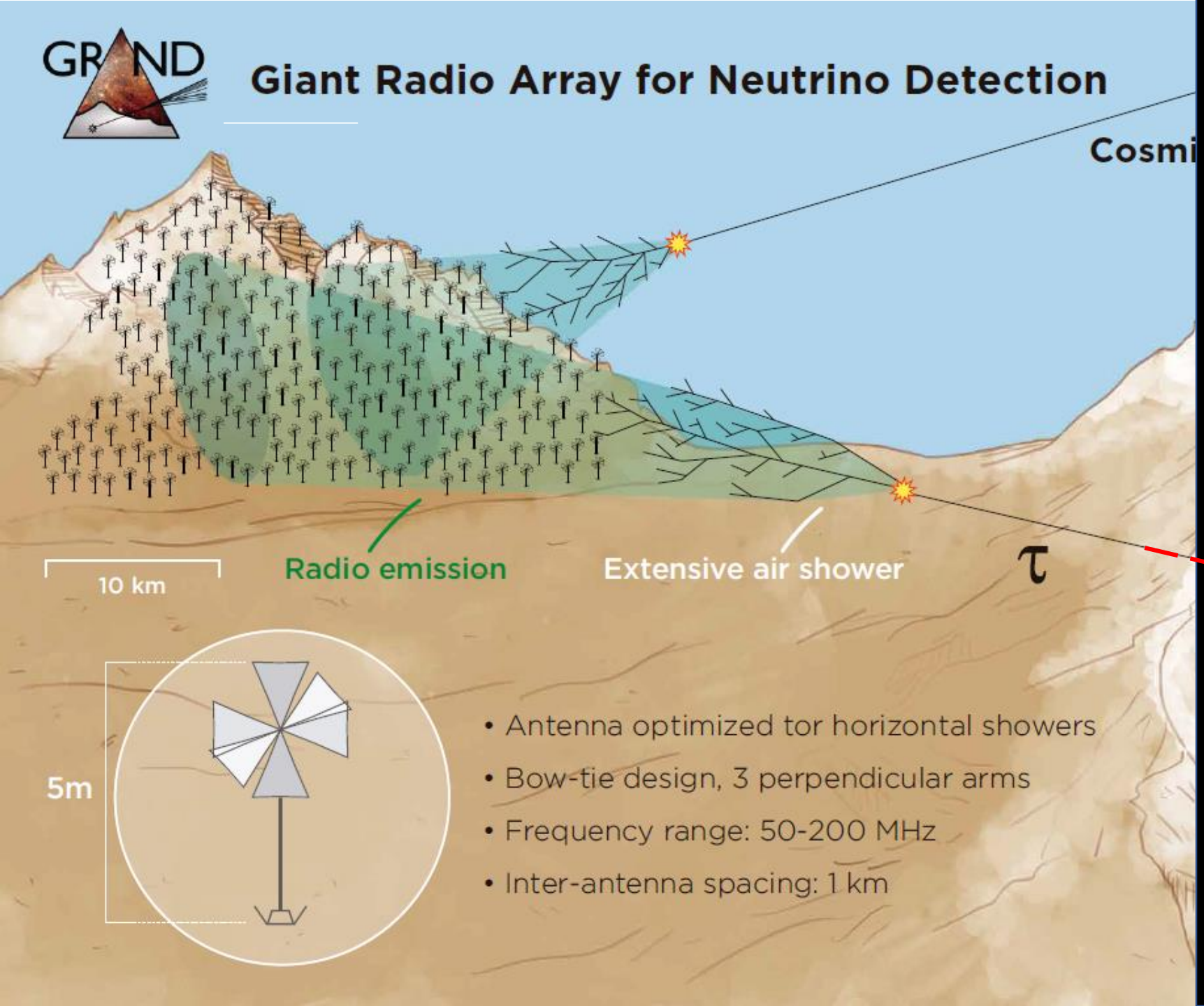

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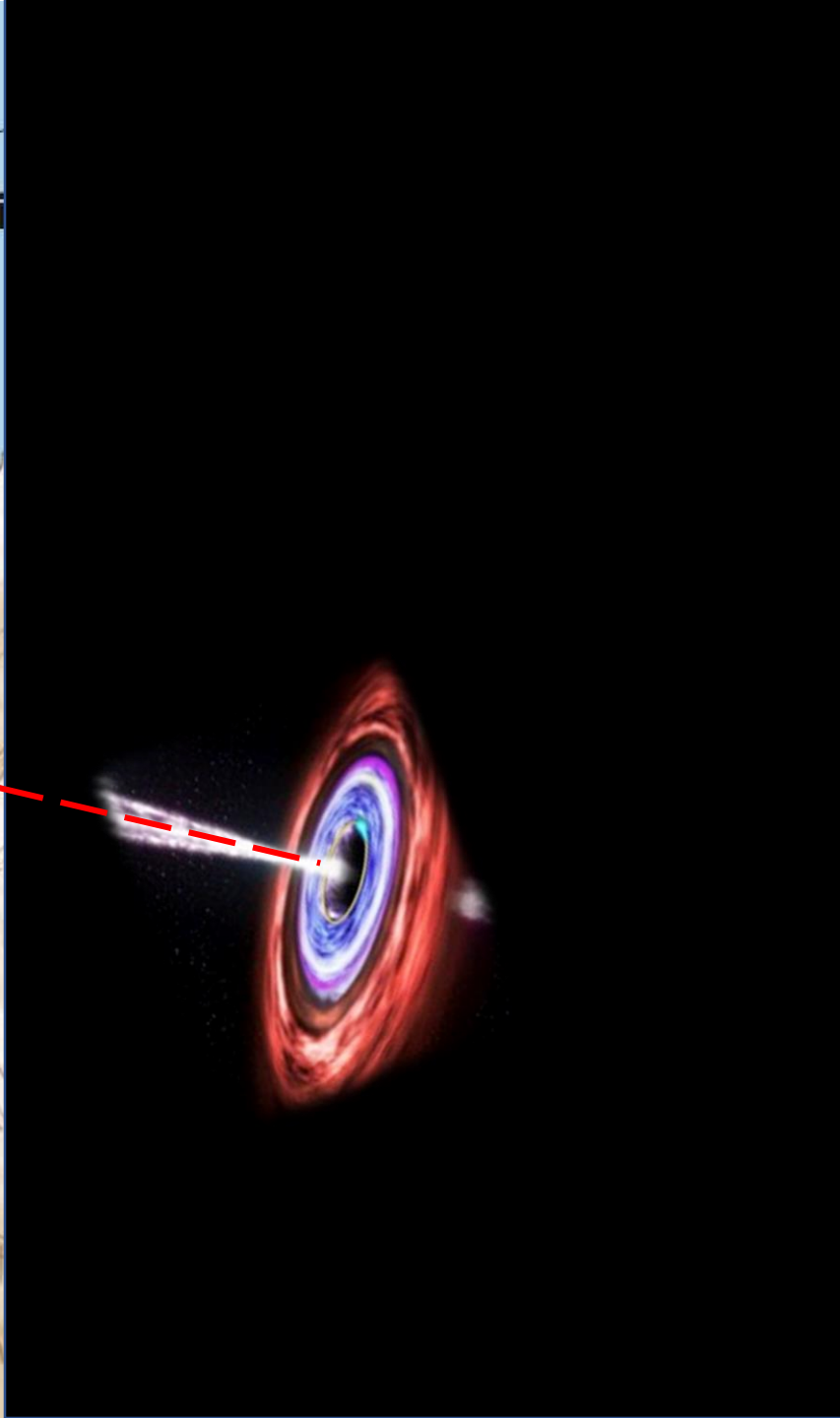

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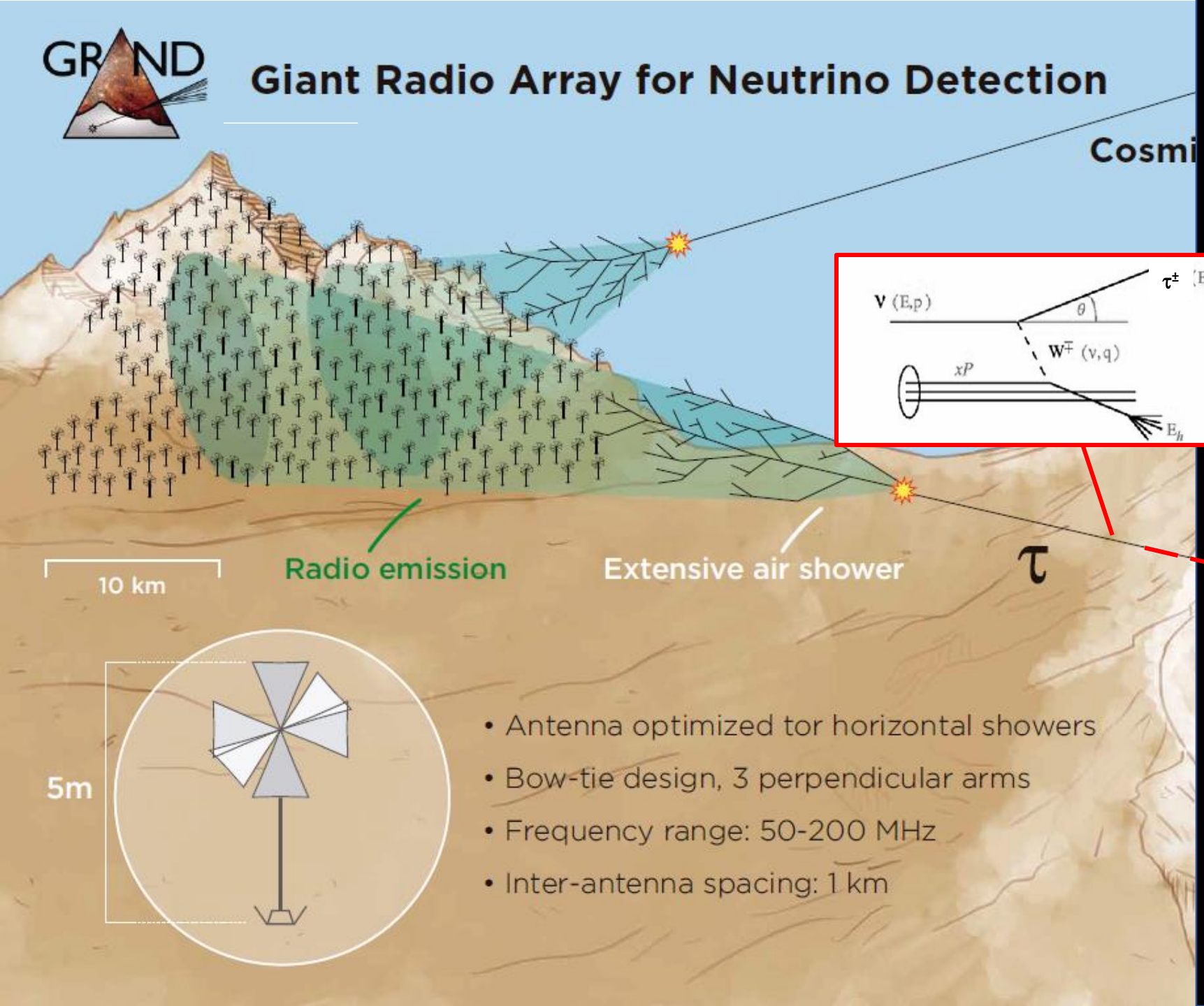

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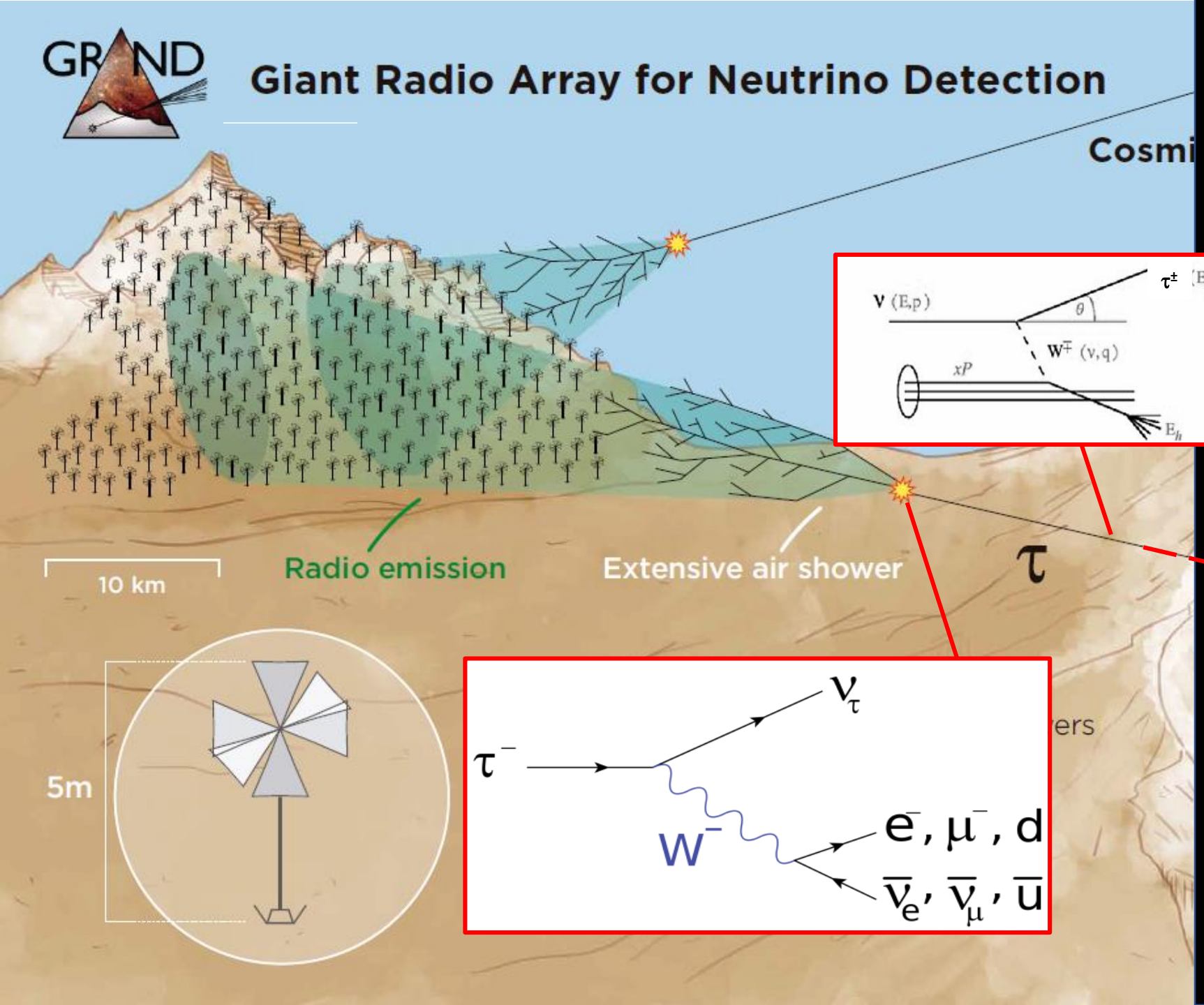
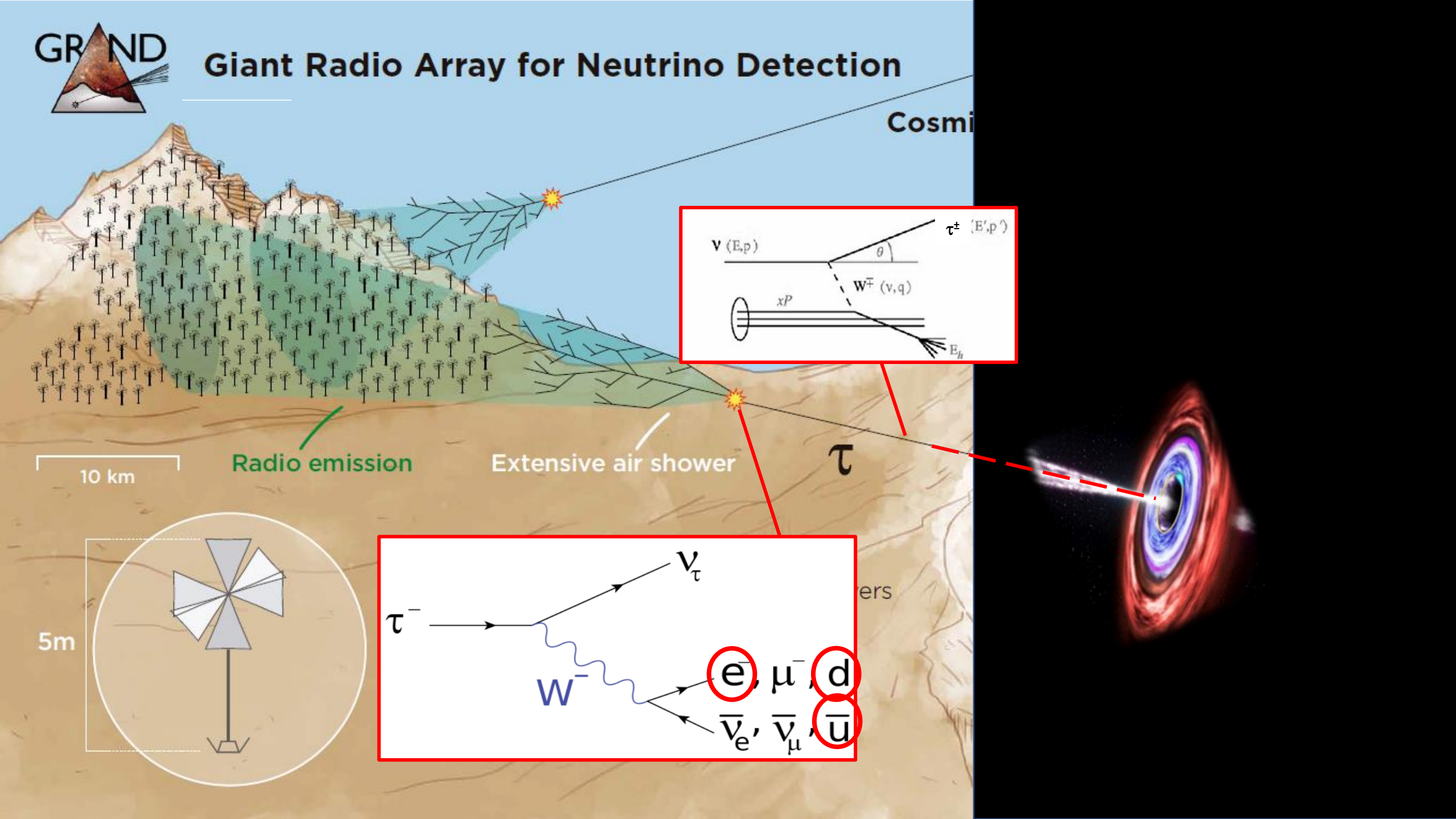



GRAND
Giant Radio Array for Neutrino Detection
Cosmi
10 km
Radio emission
Extensive air shower
τ
5m
ν (E,p)
τ± (E',p')
θ
W∓ (ν,q)
xP
E_h
τ⁻
ν_τ
W⁻
e⁻, μ⁻, d
ν̄_e, ν̄_μ, ū

The GRAND proposal

- Huge effort for end-to-end simulation

DANTON Niess & OMH arXiv:1810.01978

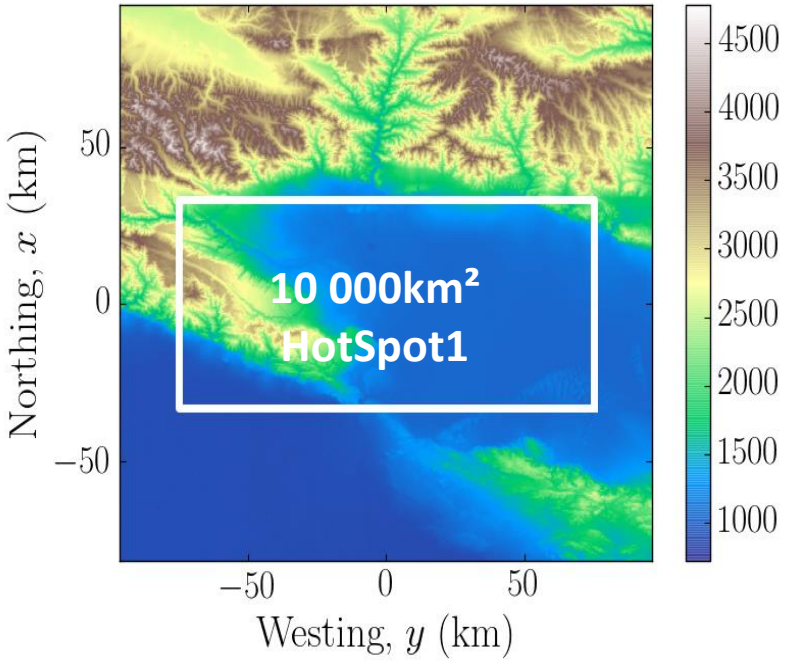
RadioMorphing Zilles et al. arXiv:1811.01750, Chiche et al., ICRC2021

on a 10000 antennas hotspot (GRAND10k)

➔ Sensitivity in IceCube2015 range.

- **Go for x20!! ➔ Network of o(20) subarrays of o(10000) antennas with sparse density (1/km²) at various favorable locations around the world (« hotspots »)**
- Sensitivity of full array good enough for GRAND to detect cosmogenic neutrinos for standard hypothesis
- Also a GREAT tool for UHECRs

See Alvarez-Muniz et al., arXiv:1810.09994



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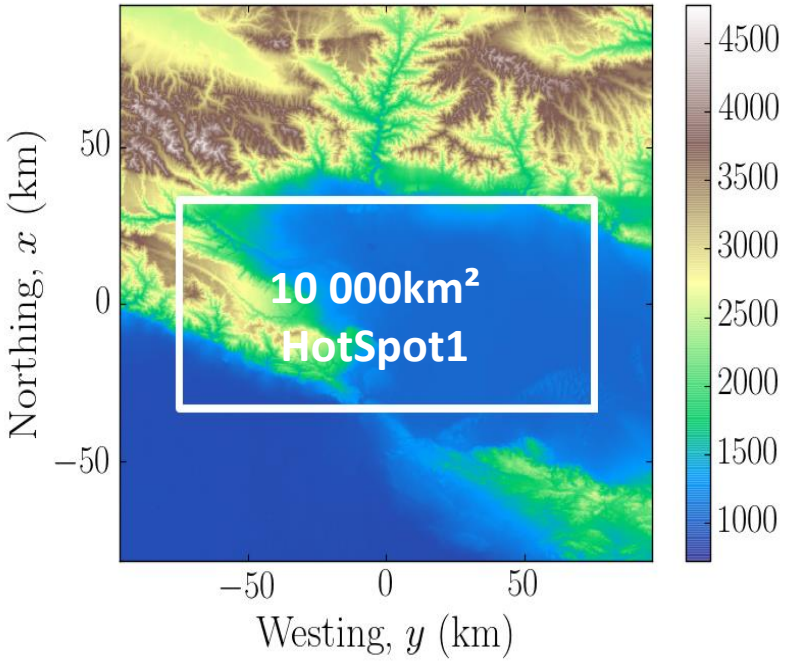
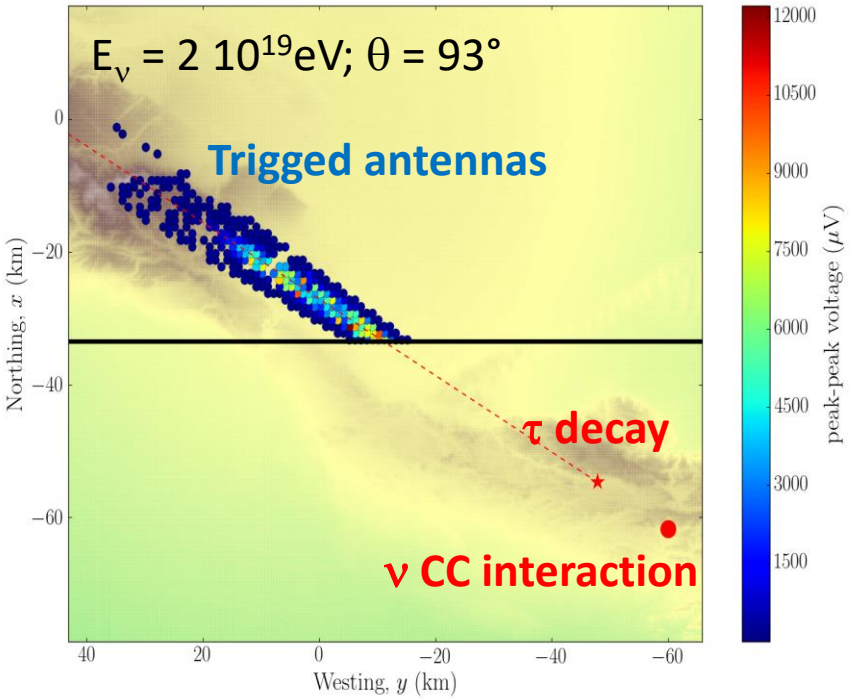


A simulated neutrino event in a GRAND hotspot



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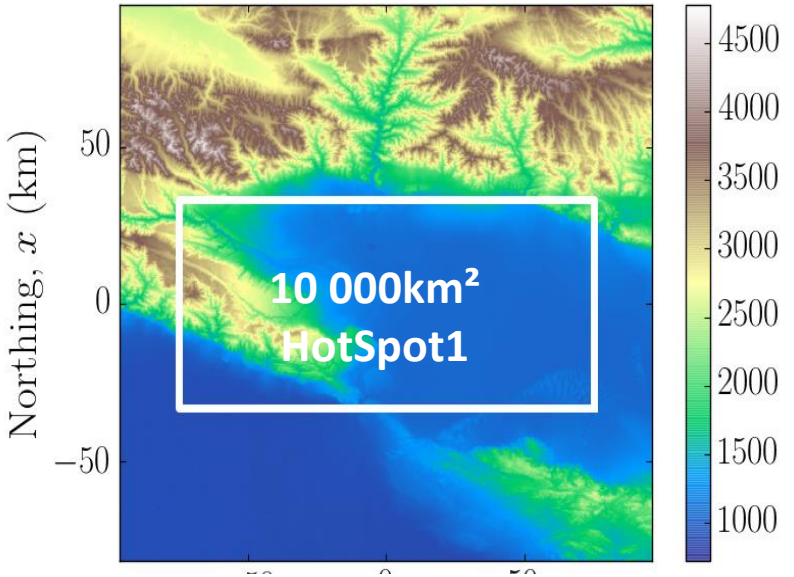

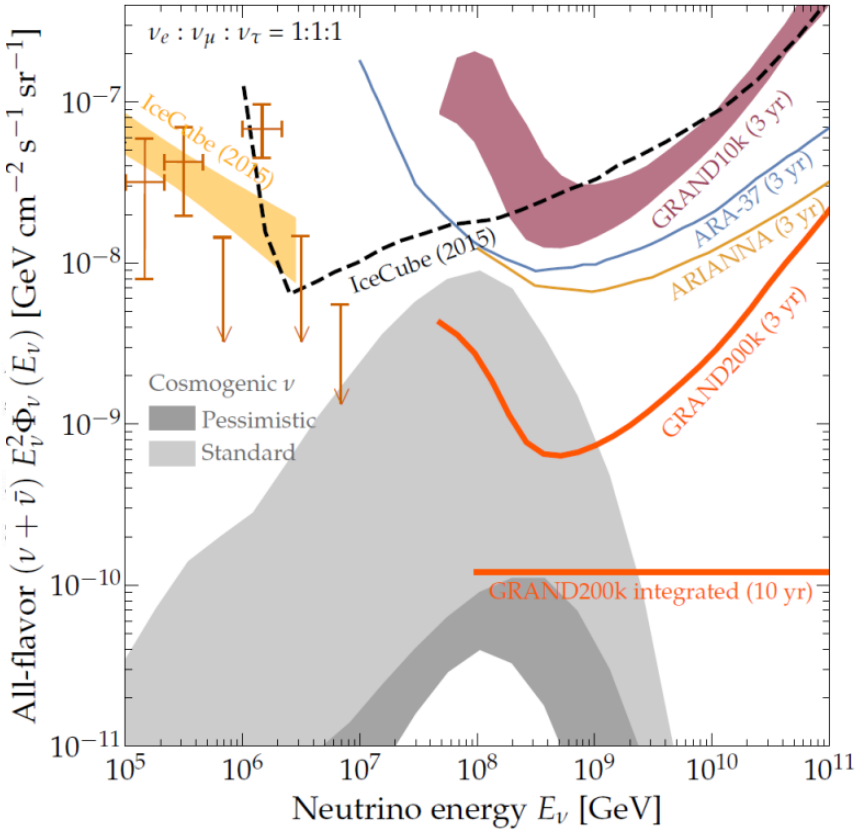

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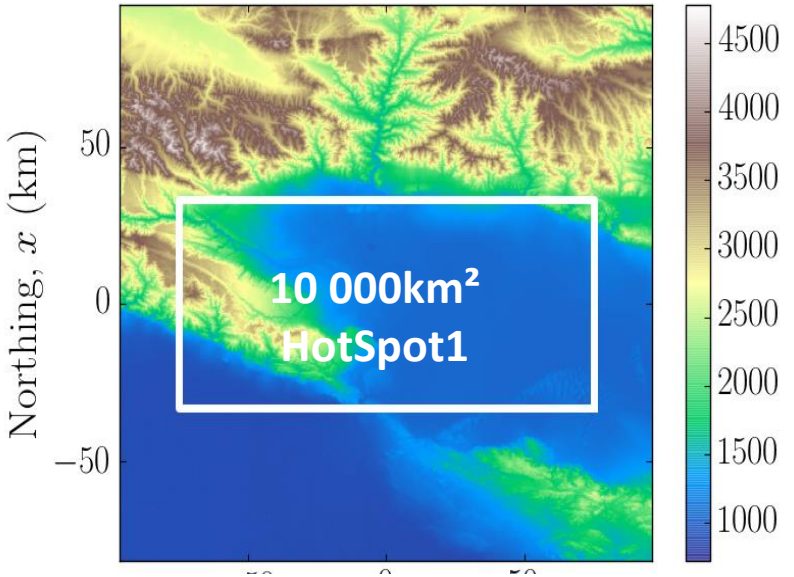

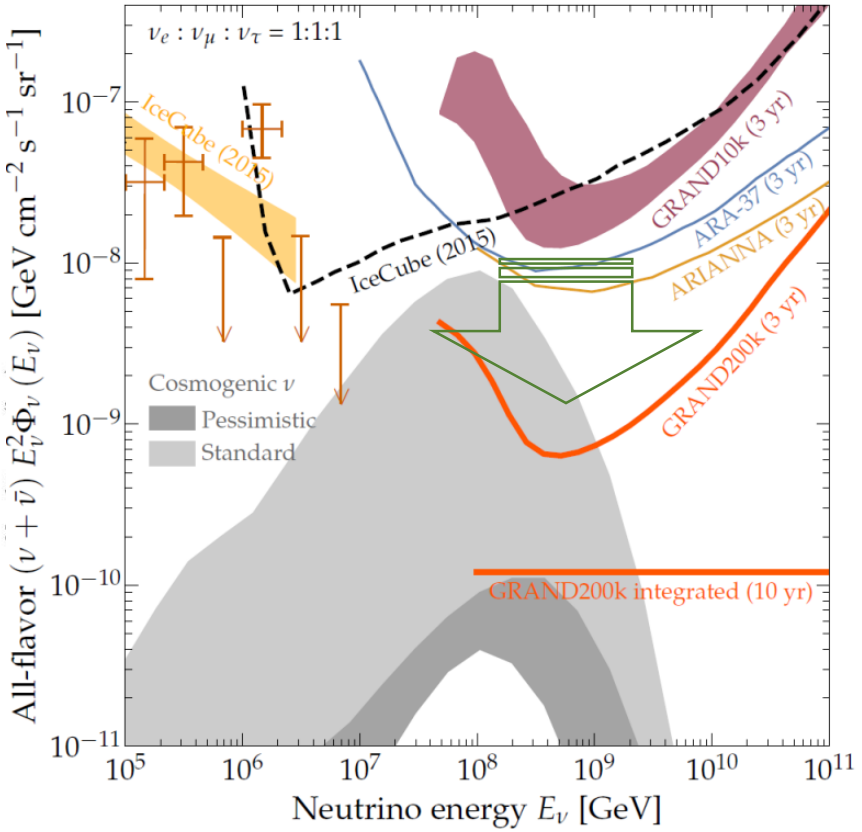

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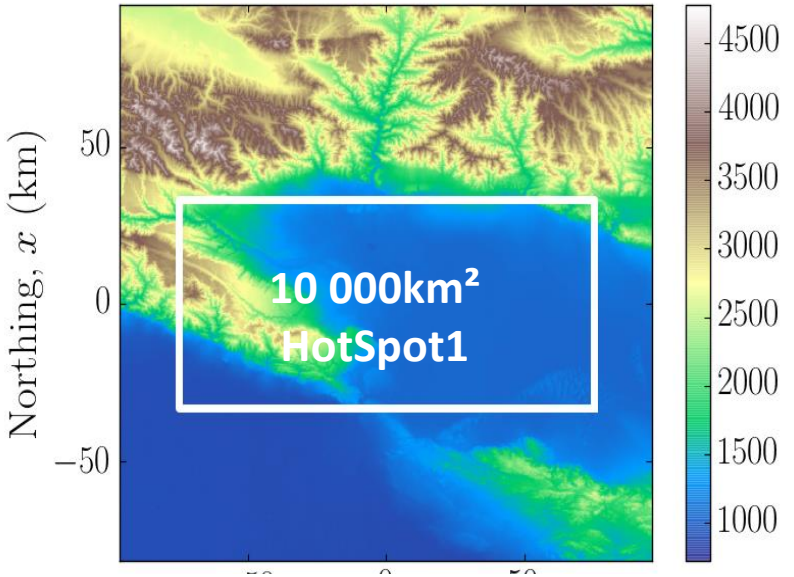

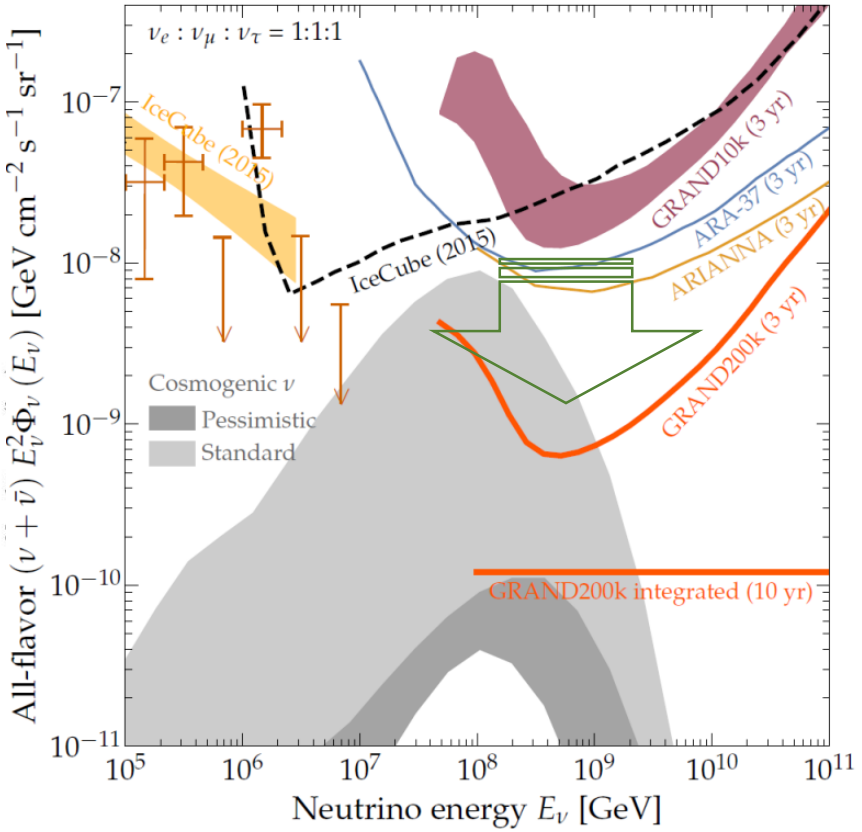

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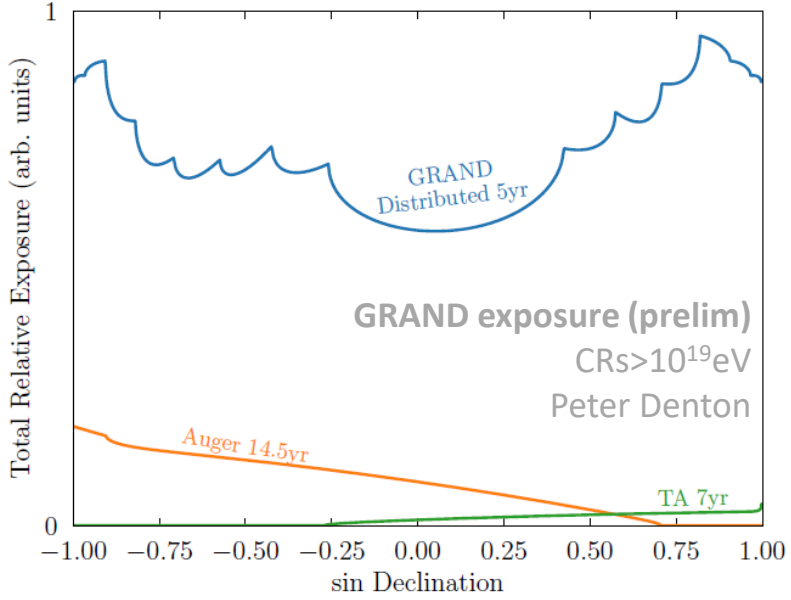
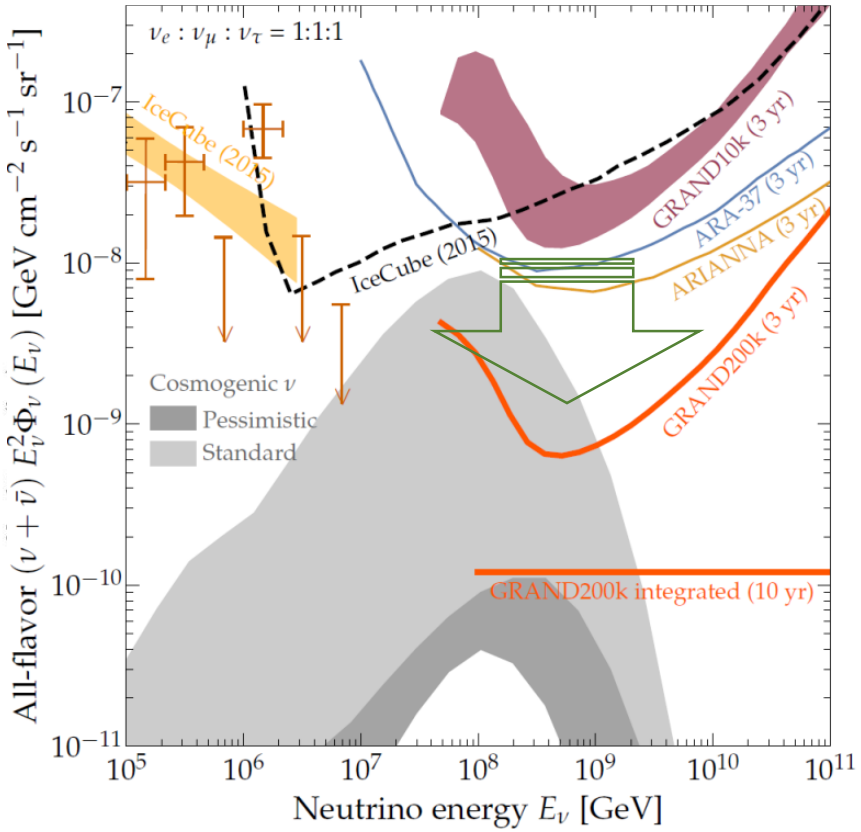




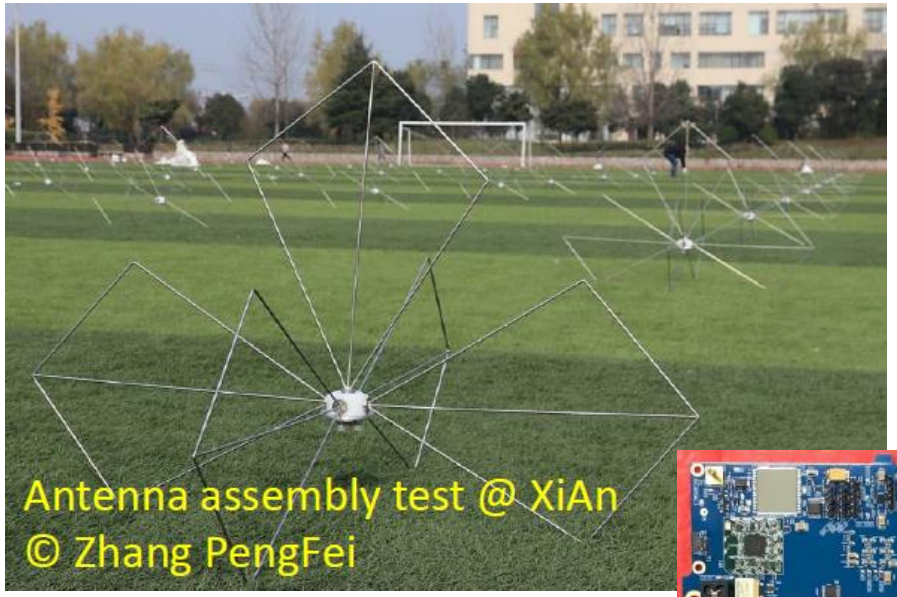
GRANDProto300

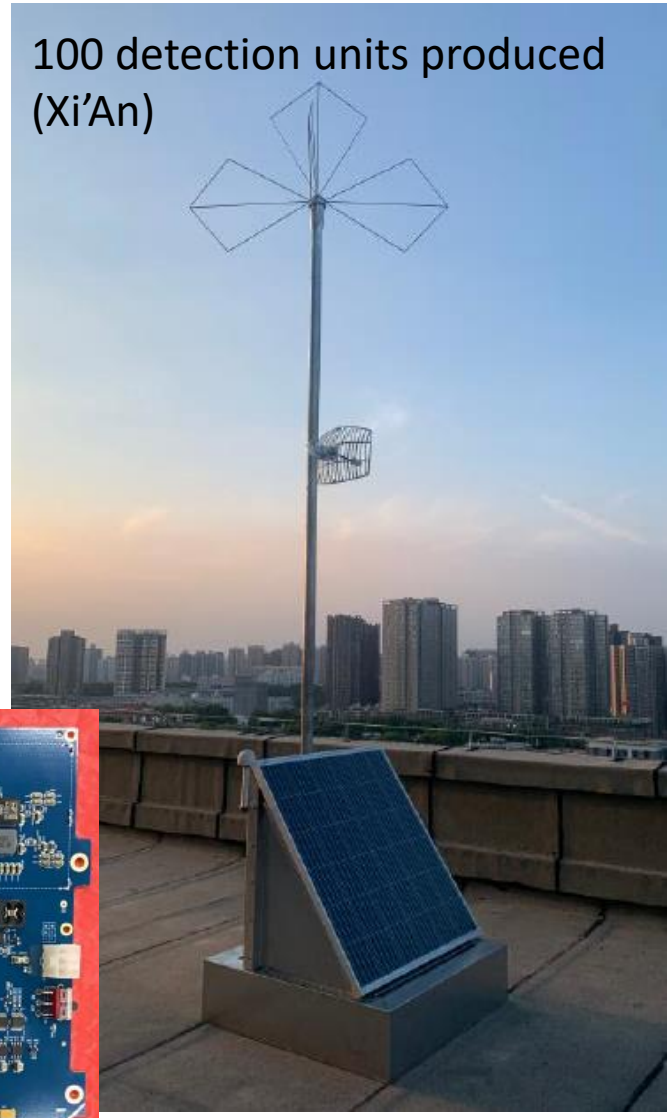
- **A pathfinder for GRAND:**
  - Validate principle of autonomous radiodetection of inclined air showers with a **300 antenna-array over 200km²**
  - Determine performances for shower identification, reconstruction (direction, nature and energy)
  - Develop procedure for calibration & monitoring (time and amplitude). Evaluate ground effects.
  - Testbench for trigger and data transfer for later stages.
- **A beautifull tool for physics**
  - Denser **infill** to reach energies down to $10^{16.5}$eV
  - Complemented by **ground array** for independent muon measurement

  ➔ Clean(er) measurement of composition & energy + larg stats in $10^{16.5}$-10^{18}eV

GP300 production status

- 100 units now ready for deployment.
- **Looking forward to play with data!** ☺

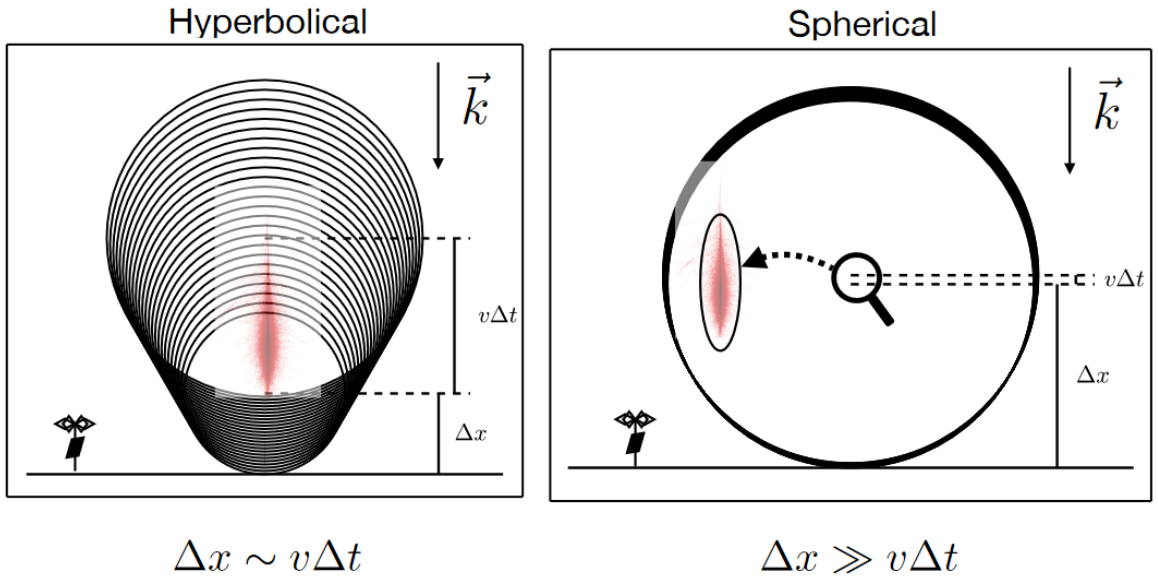


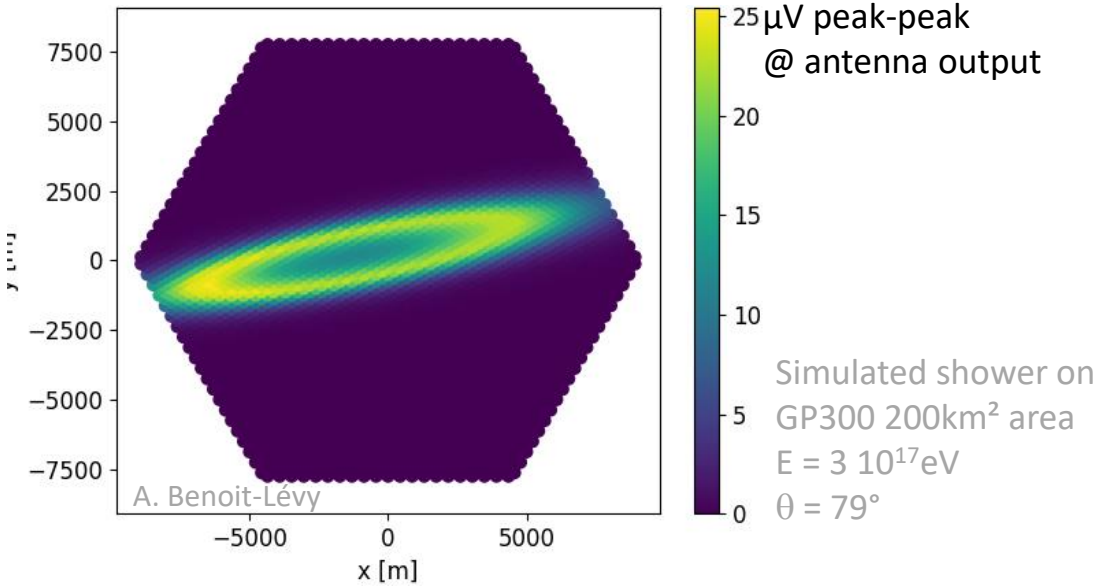


Front-End electronics
(dev: Nijmegen, prod: NAOC, tests: PMO)
500MS/s digitization
+ FPGA/CPU

Reconstruction of inclined showers with an extended radio array

- Core work of French GRAND group [PhD works of V. Decoene (2017-2020) & Simon Chiche (2020-)]
  https://hal.archives-ouvertes.fr/tel-02991529, ICRC2021: https://arxiv.org/abs/2108.00032, https://pos.sissa.it/395/194/pdf
- Very inclined geomery (θ>80°)
  ➔ Very distant shower (Xmax >50km from ground) ➔ radio emission by shower can be considered as point like
  ➔ Very large footprint ➔ excellent resolution on radio source position ➔ proxy for primary nature





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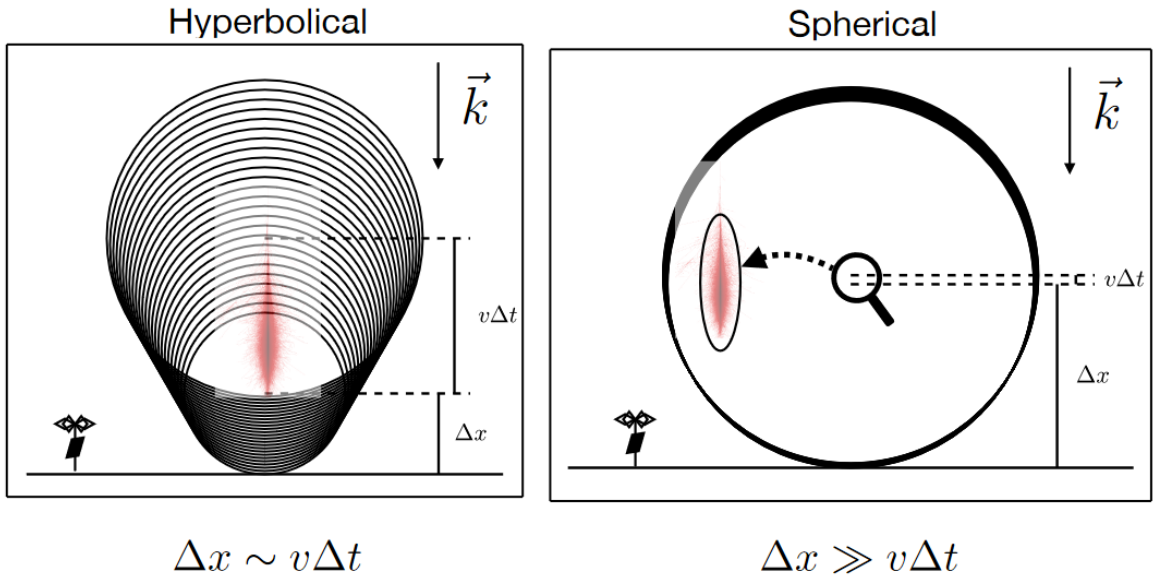
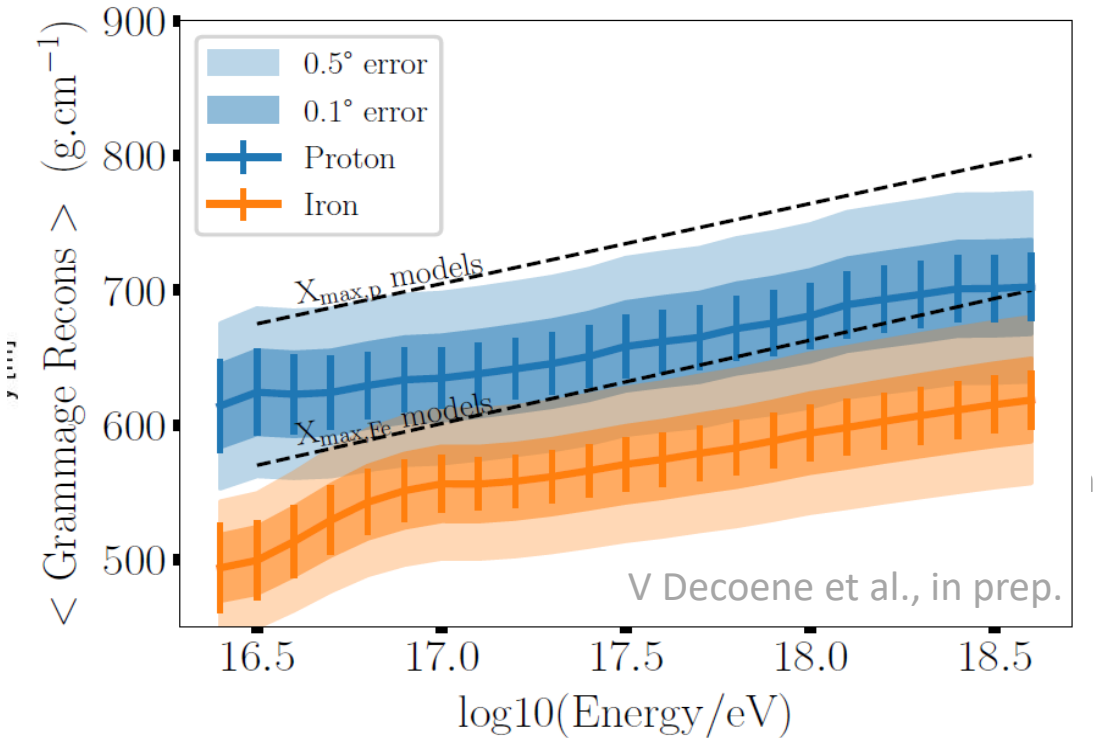
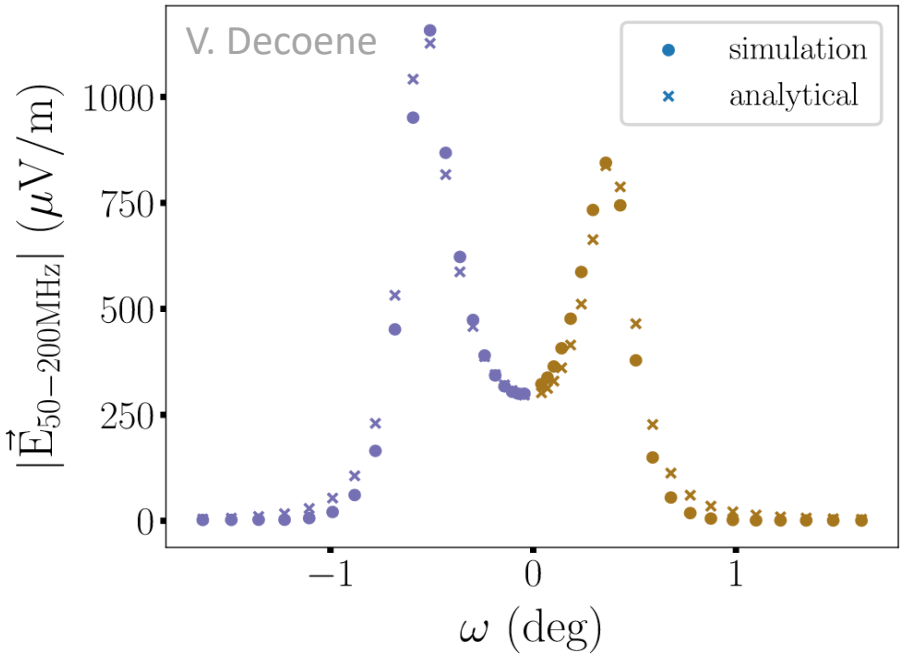




Reconstruction of inclined showers with an extended radio array

- Analytical description of amplitude profile could be written = f(direction, energy, …)
- Allows for reconstruction of direction of origin with resolution around 0.1°



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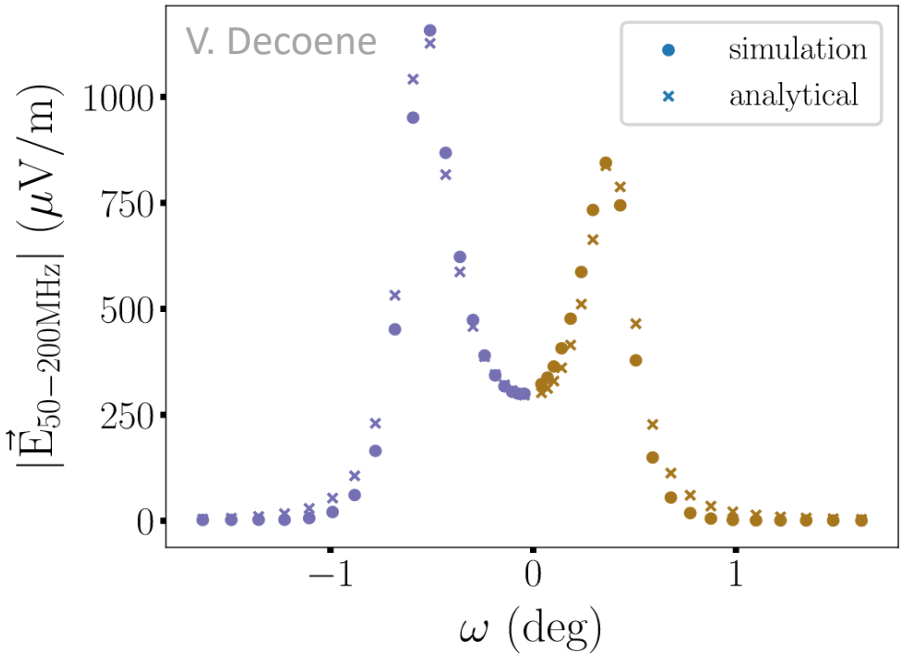

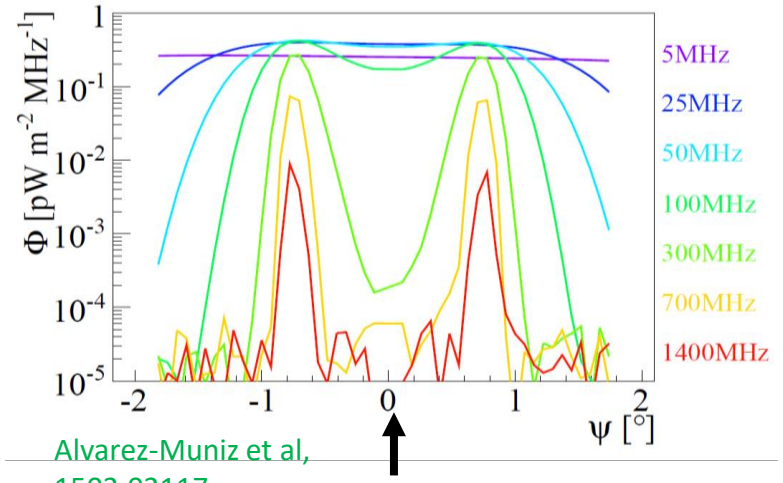

Alvarez-Muniz et al, 1502.02117

Core position

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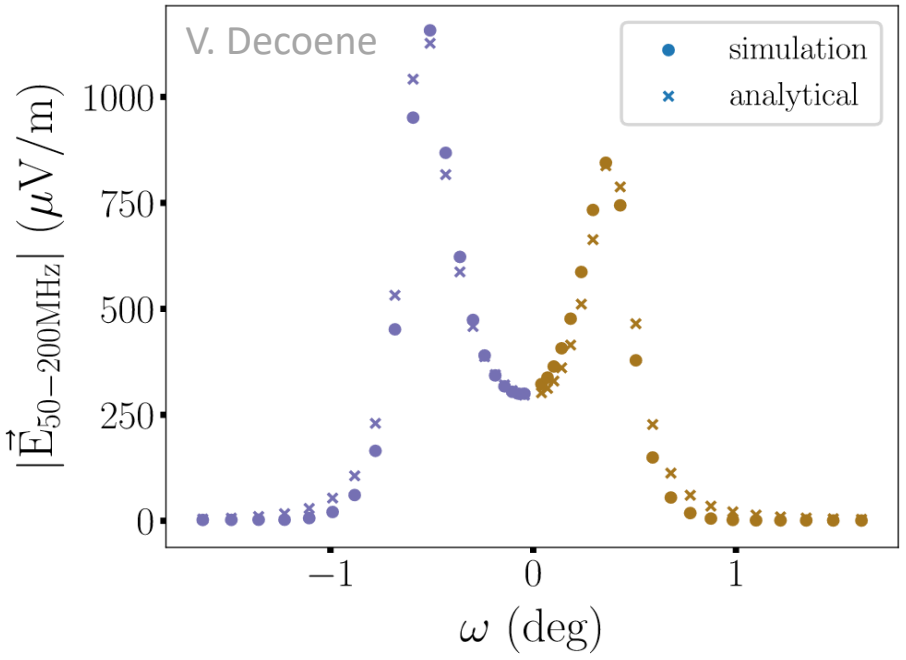
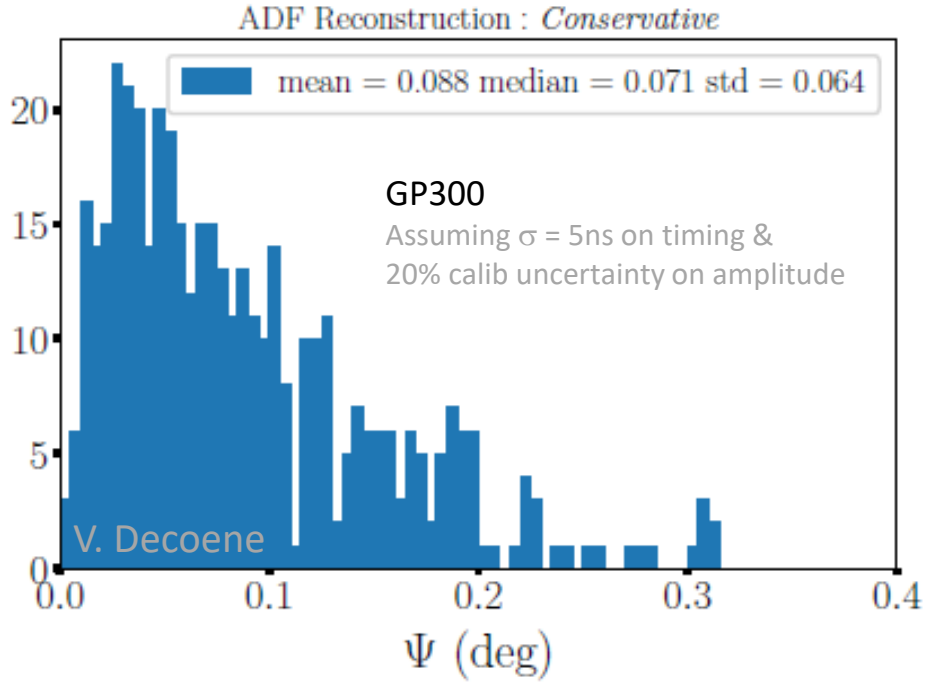
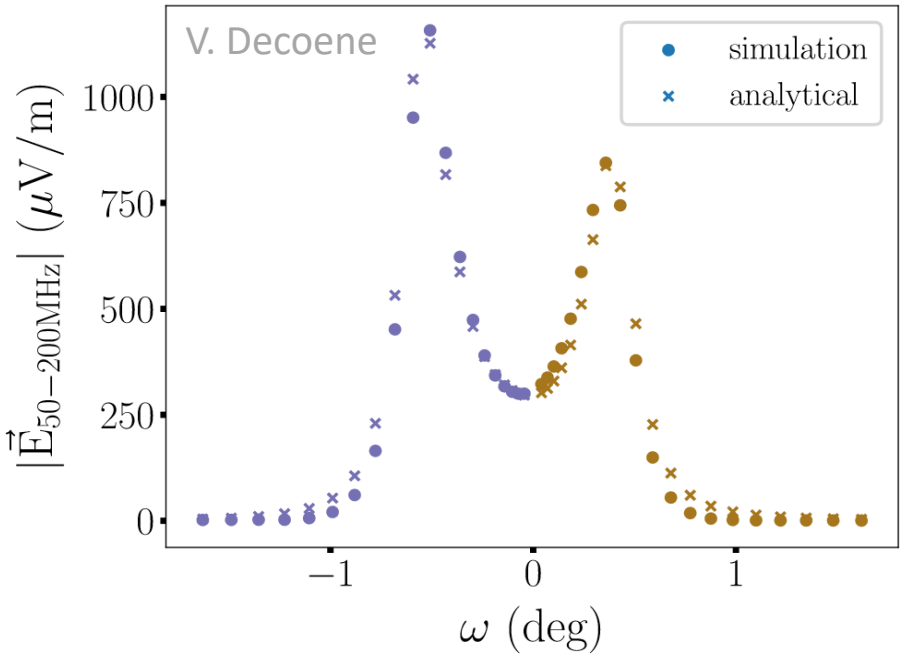
- Allows for reconstruction of direction of origin with resolution around 0.1°

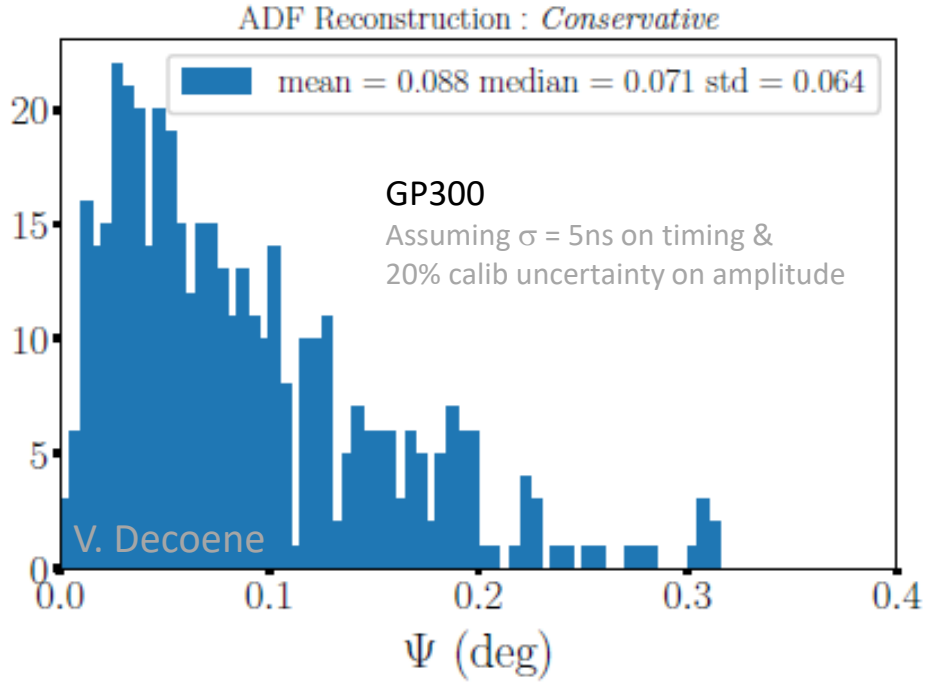




Reconstruction of inclined showers with an extended radio array

- Analytical description of amplitude profile could be written = f(direction, energy, …)
- Allows for reconstruction of direction of origin with resolution around 0.1°

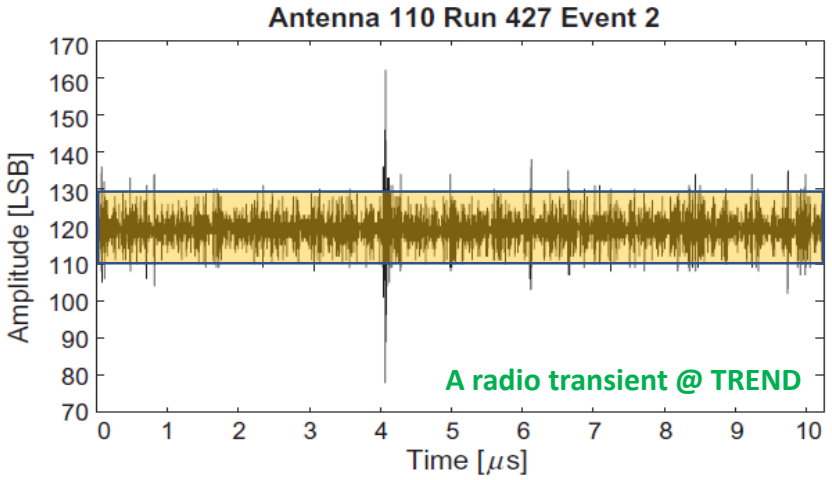




Shower geometry & detector layout in GRAND differ signifiantly from standard radio-detectors (AERA, LOFAR)
➔ Complete new analysis allows for optimized performances for reconstruction.

GP300 as a testbench for GRAND10k

- Key issue for GRAND10k (10’000 antennas over 10’000km²): trigger (ie pulse selection) & data collection



<u>Past & present experiments (TREND, AERA, GP300):</u>
- Trigger (mostly) based on signal-over threshold + search for coincidences
- Full time traces are recorded (few kBy/antenna)

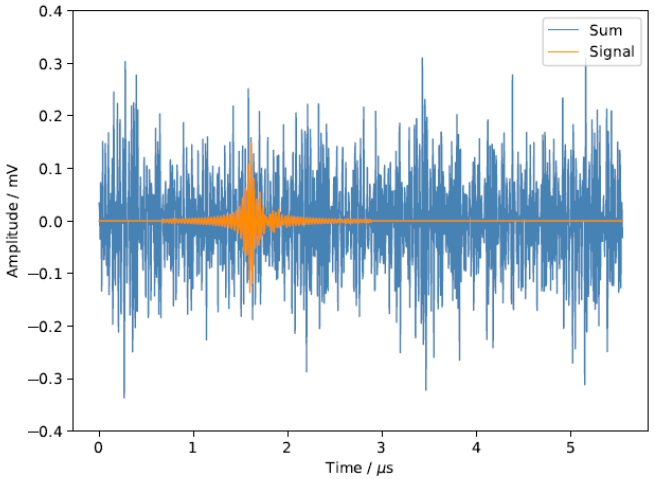
BUT
- Shower radio signal very well known (simulations) & noise constantly measured
- Only few infos used in reconstruction (time, amplitude, polar)

➔ **should be possible to do much better both for trigger & data transfer.**

<u>Online</u> signal identification through:
- analytical methods (template fitting, optimal filtering)
- Machine learning

➔ Also excellent for threshold improvement!

➔ S. Le Coz as post-doc @ LPNHE + collab with CEA-LIST

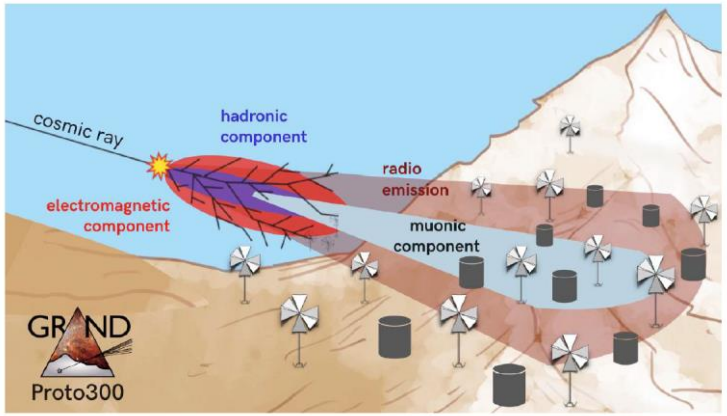


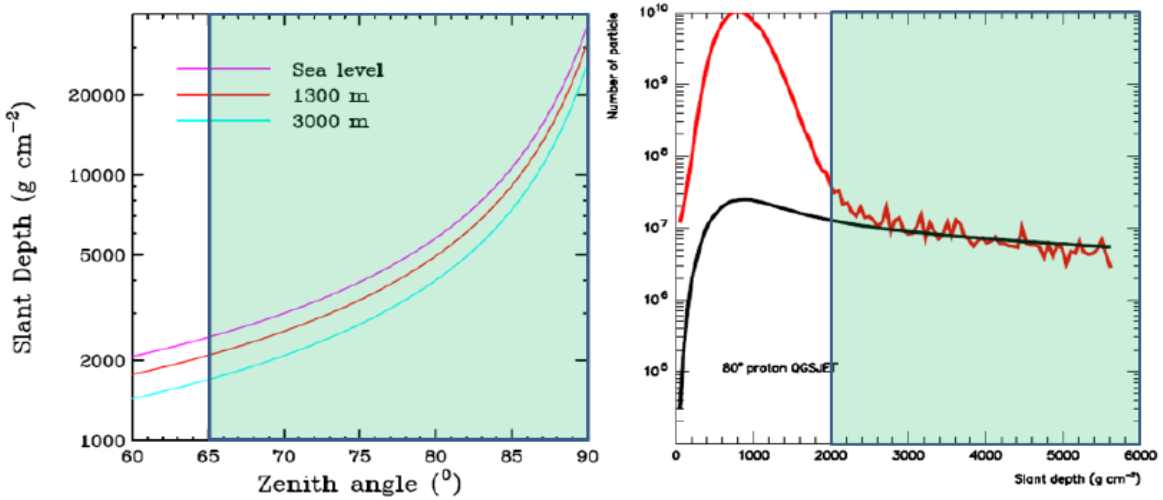
Erdmann et al, astro-ph/1901.04079

GP300 as a science instrument

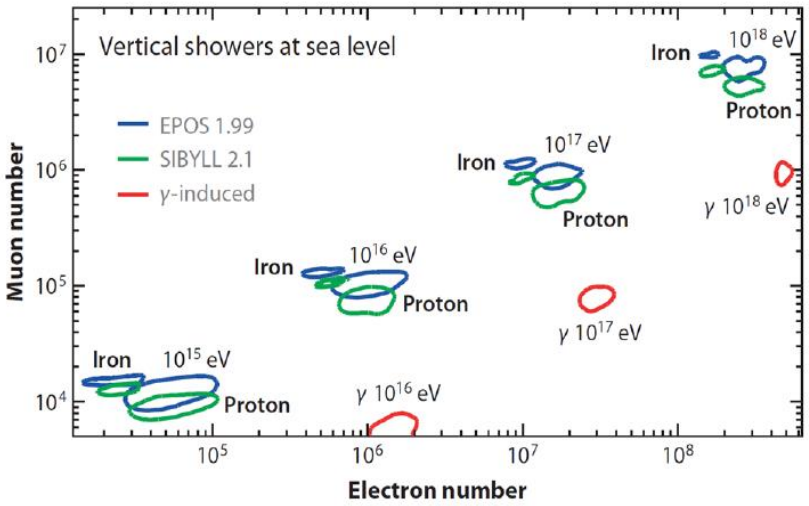
- GP300 to be complemented with (self-triggered) ground array:

➔ independant measurement of electronic (radio array) & muon (ground array) components for each shower





Zas, New Journal of Physics 7, 1302013130 (2005).



Engel et al., Annual Rev of Nuclear and Part. Science 61, 467 (2011)

- Great tool for CR composition study in the transition region
- Also great for gammas: initiated study to characterize <u>transient</u> Galactic gamma emissions + possible detection in GP300

Conclusion

- GRAND is a proposal for the detection of UHE neutrinos in the next decade
- GRANDProto300 as a pathfinder for GRAND
  - Testbench to develop & test innovative reconstruction methods
  - Pathfinder for advanced trigger methods
  - Science tool for cosmic particles in $10^{16.5}$-10^{18} eV
    - GP300 as a gamma ray detector?