Panorama de l'astronomie neutrino d'Ultra Haute Energie ($E>10^{16}$eV)

Atelier de la communauté française de recherche sur le rayonnement cosmique

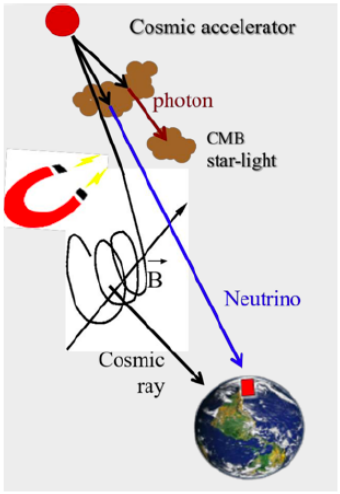
APC, 26-28 mars 2018

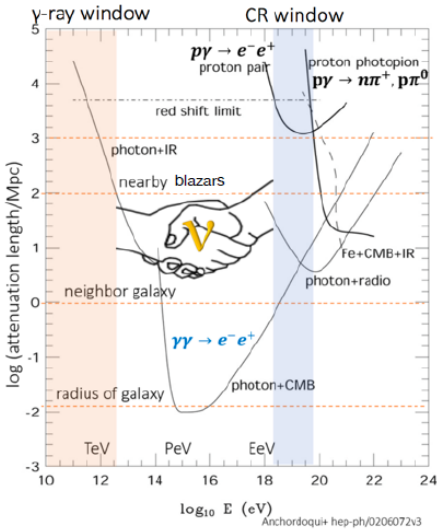
Olivier Martineau-Huynh, LPNHE, IN2P3 & NAOC, CAS omartino@in2p3.fr

Why neutrinos?

- Clean probe of the Violent Universe & direct bound to UHECRs

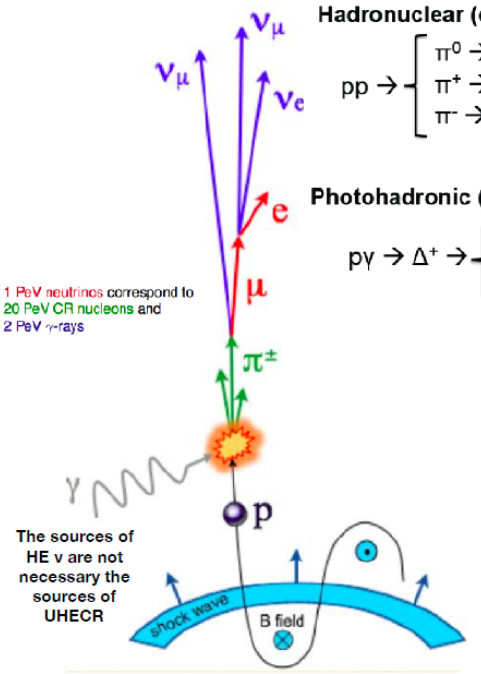
NEUTRINO AS COSMIC MESSENGER





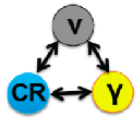
Neutrino: Neutral and weak, point to the source carrying information from the deepest parts.

HE NEUTRINO PRODUCTION



Hadronuclear (e.g. star burst galaxies and galaxy clusters)

$pp \to \begin{cases} \pi^0 \to \gamma\gamma \\ \pi^+ \to \mu^+ \nu_\mu \to e^+ \nu_e \nu_\mu \bar{\nu}_\mu \\ \pi^- \to \mu^- \bar{\nu}_\mu \to e^- \bar{\nu}_e \bar{\nu}_\mu \nu_\mu \end{cases}$



Photohadronic (e.g. gamma-ray bursts, active galactic nuclei)

$p\gamma \to \Delta^+ \to \begin{cases} p\,\pi^0 \to p\,\gamma\,\gamma \\ n\,\pi^+ \to n\,\mu^+\,\nu_\mu \to n\,e^+\,\bar{\nu}_e\,\bar{\nu}_\mu\,\nu_\mu \end{cases}$

cosmic ray + gamma

cosmic ray + neutrinos

Neutrino flavour ratio at source:

pion-muon decay

$\nu_e : \nu_\mu : \nu_\tau \sim 1 : 2 : 0$

Oscillations average out over cosmic baselines

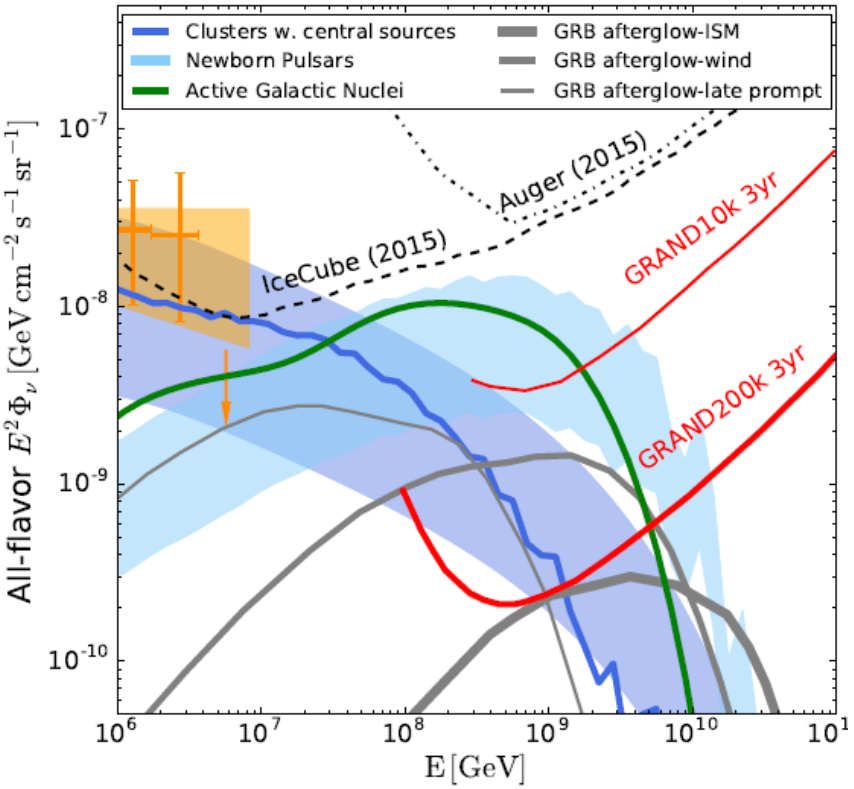
$\nu_e : \nu_\mu : \nu_\tau \sim 1 : 1 : 1$

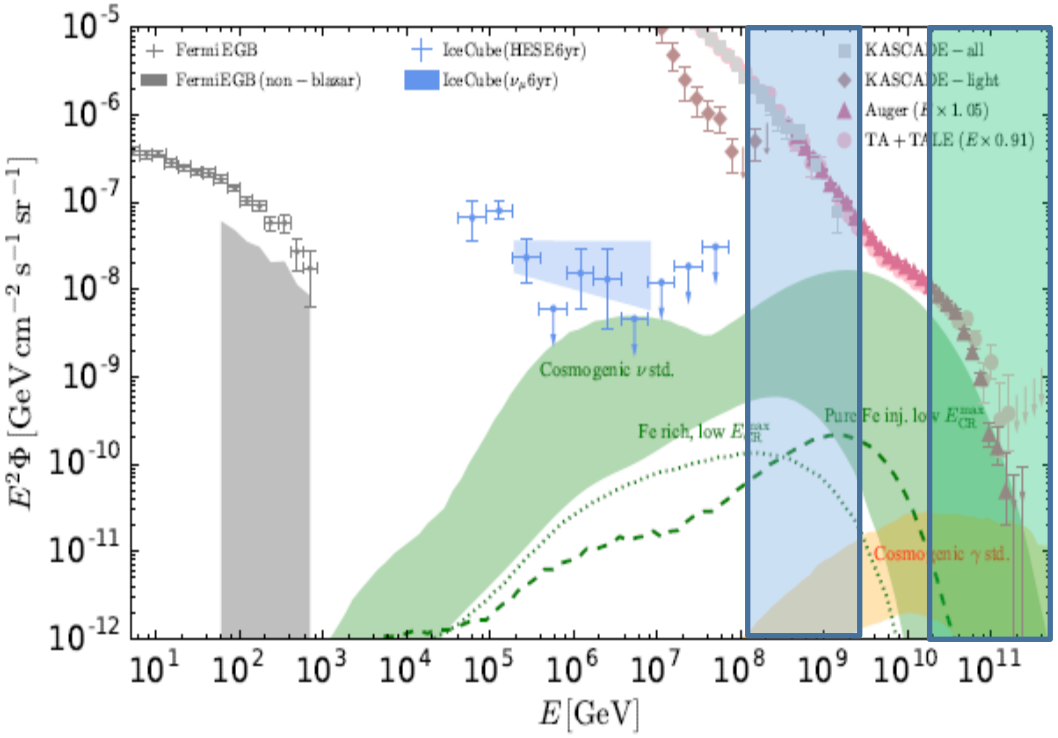
See D. Dornic presentation

*Also through interaction of UHECRs with CMB during propagation: cosmogenic neutrino (**guaranteed** flux)*

Why UHE neutrinos?

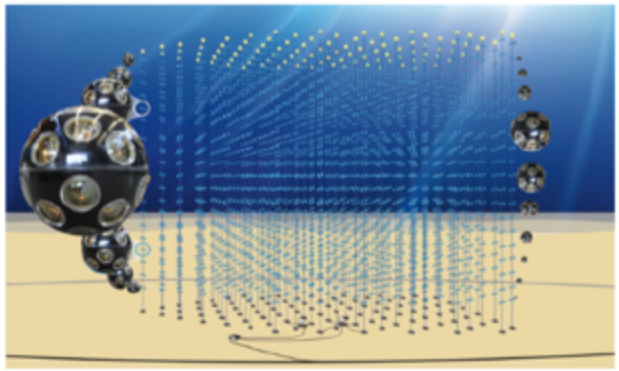
- Extend energy range to UHE to better constrain models.
- Direct link to UHECRs (E_ν~5%E_{CR}).





Future project overview

complementarity,
sensitivity to
neutrino sources
"precision frontier"



KM3NeT, GVD

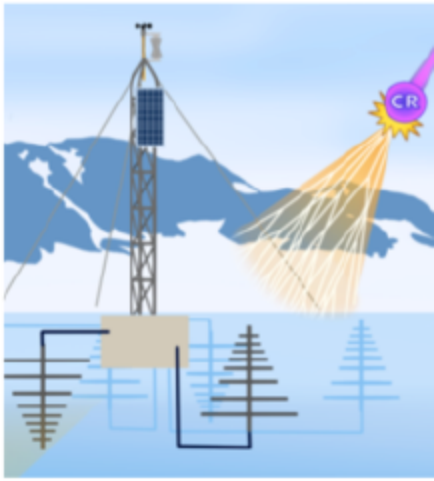
IceCube
SOUTH POLE NEUTRINO OBSERVATORY

ANTARES

PIERRE AUGER OBSERVATORY

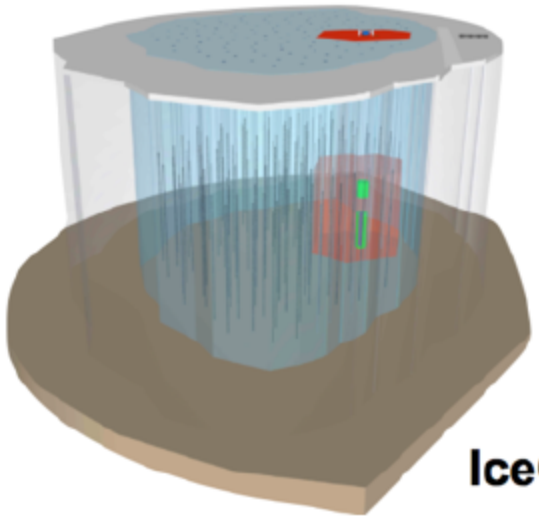
Present neutrino detectors

sensitivity at EeV
and beyond
"energy frontier"



**ARA, ARIANNA,
EVA, GRAND**

sensitivity at
PeV energies
"intensity frontier"



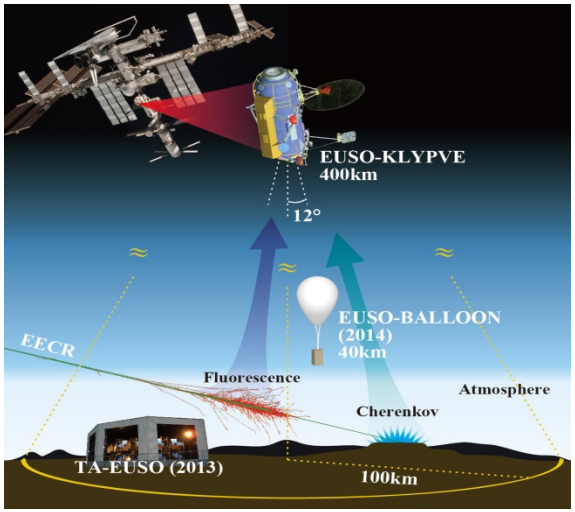
IceCube-Gen2

Kowalski@TeVPA2017

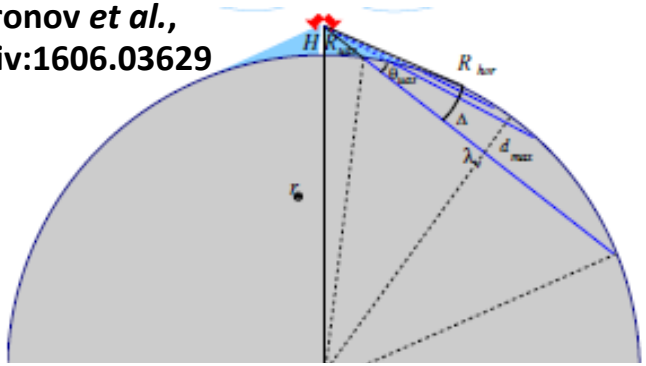
credit: M. Ackerman

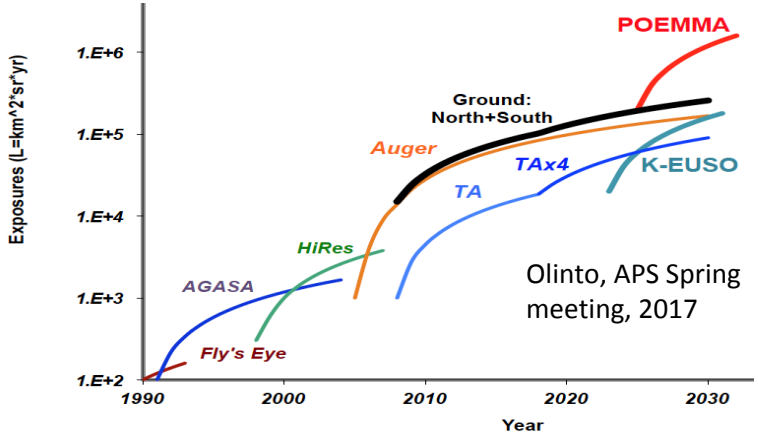
Satellites projects

- POEMMA, K-EUSO & pathfinder EUSO-SPB

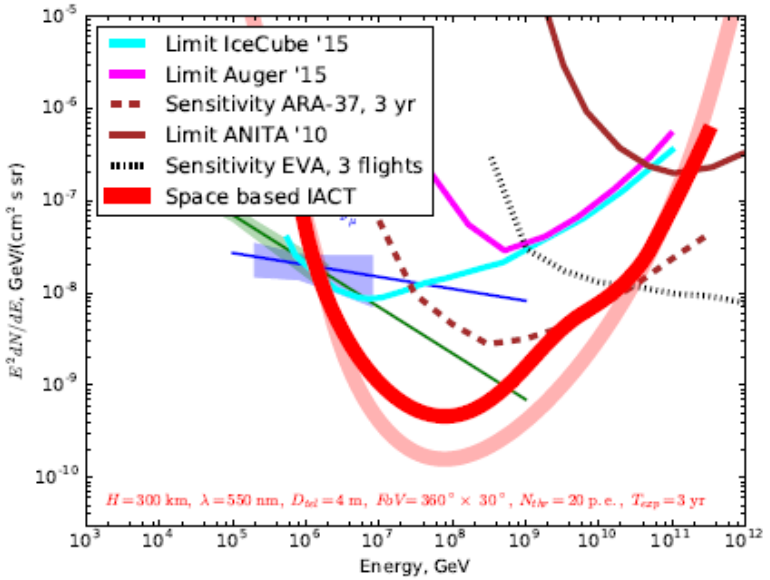


Neronov *et al.*,
arxiv:1606.03629





Olinto, APS Spring meeting, 2017



Antarctica projects

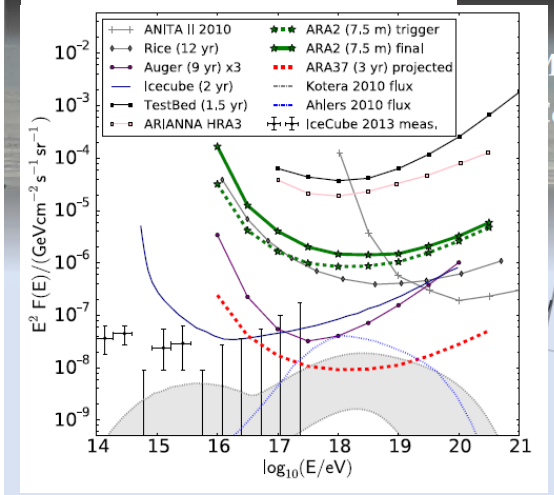
Detection of UHE Neutrinos in Ice

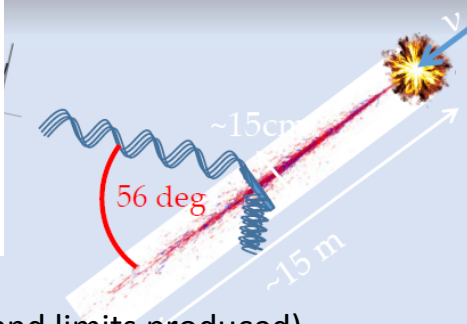
Via the Askaryan effect:
An excess negative charge (~20%) built up in neutrino induced cascades through:

- **Compton scattering**
- **Other ionizing effects**

Moving current, emits electromagnetic radiation
Coherent for radio wavelength

Allison et al., arxiv:1507.0899



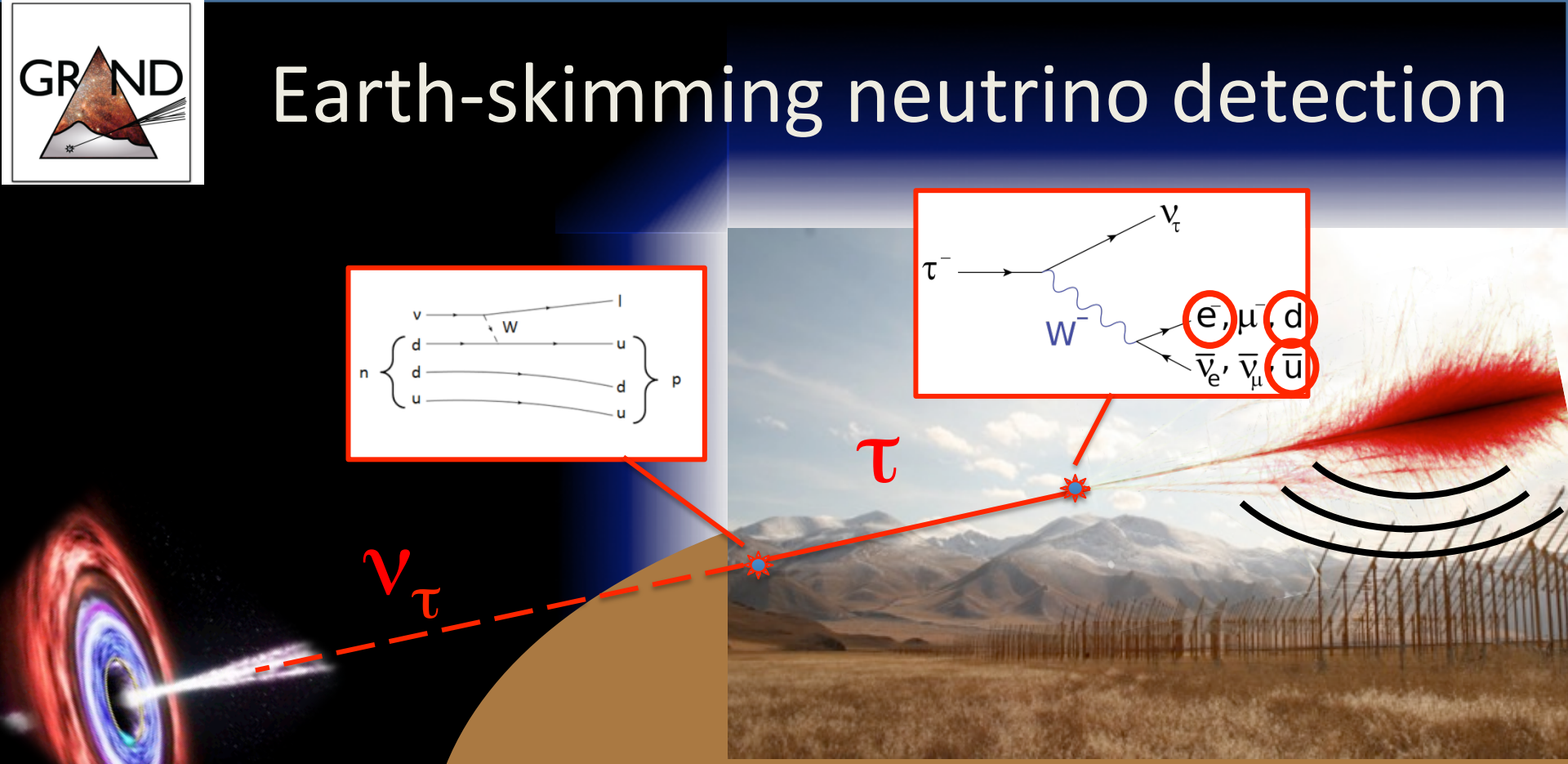


The advantages of RF detection schemes:
- → RF attenuation length in ice ~ 1 km
- → Observe big detector volume with few sensors
- → **Very cost effective means to instruments 100's of Gton of target.**

Beautifull principle
Already a lot of expertise gained (and limits produced)
Tough polar environment ➔ high cost (& limited area)
Uncertainties on signal propagation ➔ poor angular resolution

ARENA 2016 - Groningen, NL | Kael HANSON UW Madison

Earth-skimming neutrino detection



- Goal: search for cosmic neutrinos
- Detection principle:
  - ν-induced tau decays in atmosphere generate ~horizontal extensive air showers.
    [Fargion astro-ph/99066450, Bertou astro-ph/0104452]
  - Issues:
    - VERY seldom events
    - Earth-skimming trajectories (mfp_ν <1000km)

Why radio? Because it works!

- MHz radio-detection of air showers becoming a mature technique

- σ(Xmax) ~ 20g/cm²

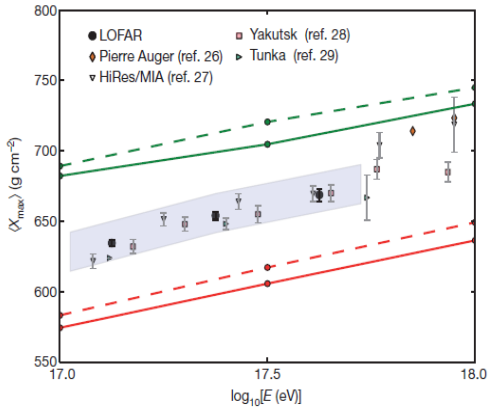
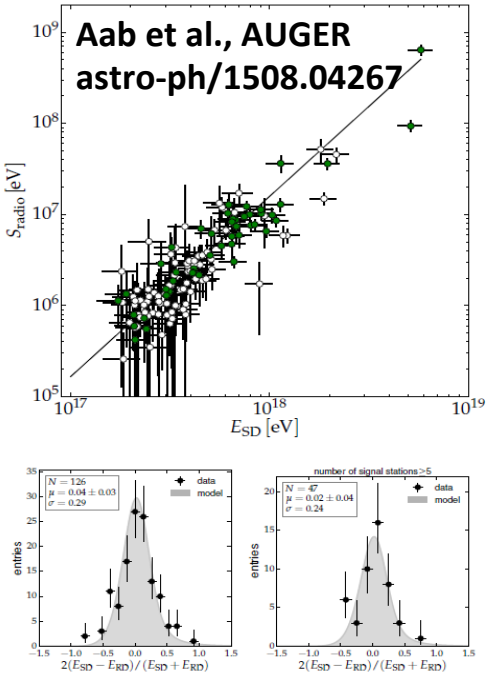


Figure 2 | Measurements of $\langle X_{max} \rangle$. Mean depth of the shower maximum X_{max} as a function of energy E for LOFAR, and for previous experiments that used different techniques[26–29]. Error bars indicate 1σ uncertainties. The systematic uncertainties are $^{+14}_{-10}$ g cm^{-2} on $\langle X_{max} \rangle$ and 27% on E, as indicated by the shaded band. The Pierre Auger Observatory[26] measures the fluorescent light emitted by atmospheric molecules excited by air-shower particles. HiRes/MIA[27] used a combination of this fluorescence technique and muon detection. The Yakutsk[28] and Tunka[29] arrays use non-imaging Cherenkov detectors. The green (upper) lines indicate $\langle X_{max} \rangle$ for proton showers simulated using QGSJETII.04 (solid) and EPOS-LHC (dashed); the red (lower) lines are for showers initiated by iron nuclei.

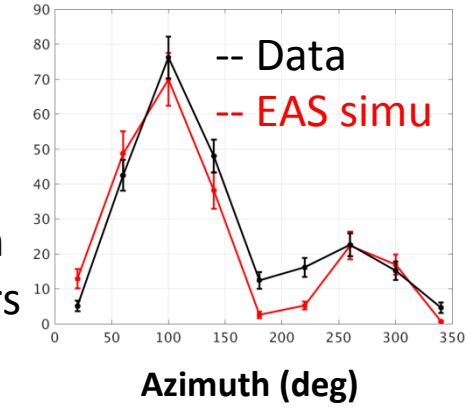
Buitink et al., LOFAR, Nature

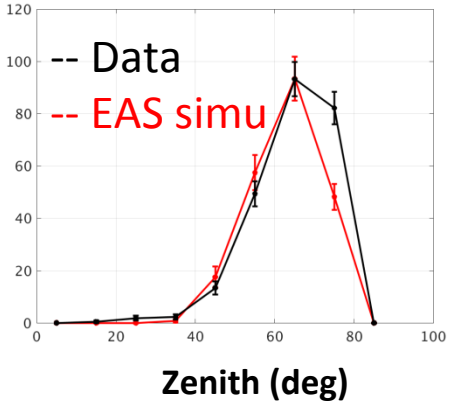
- ΔE/E<20%



- Autonomous radio-detection & identification of air showers

Le Coz et al., TREND ICRC2017



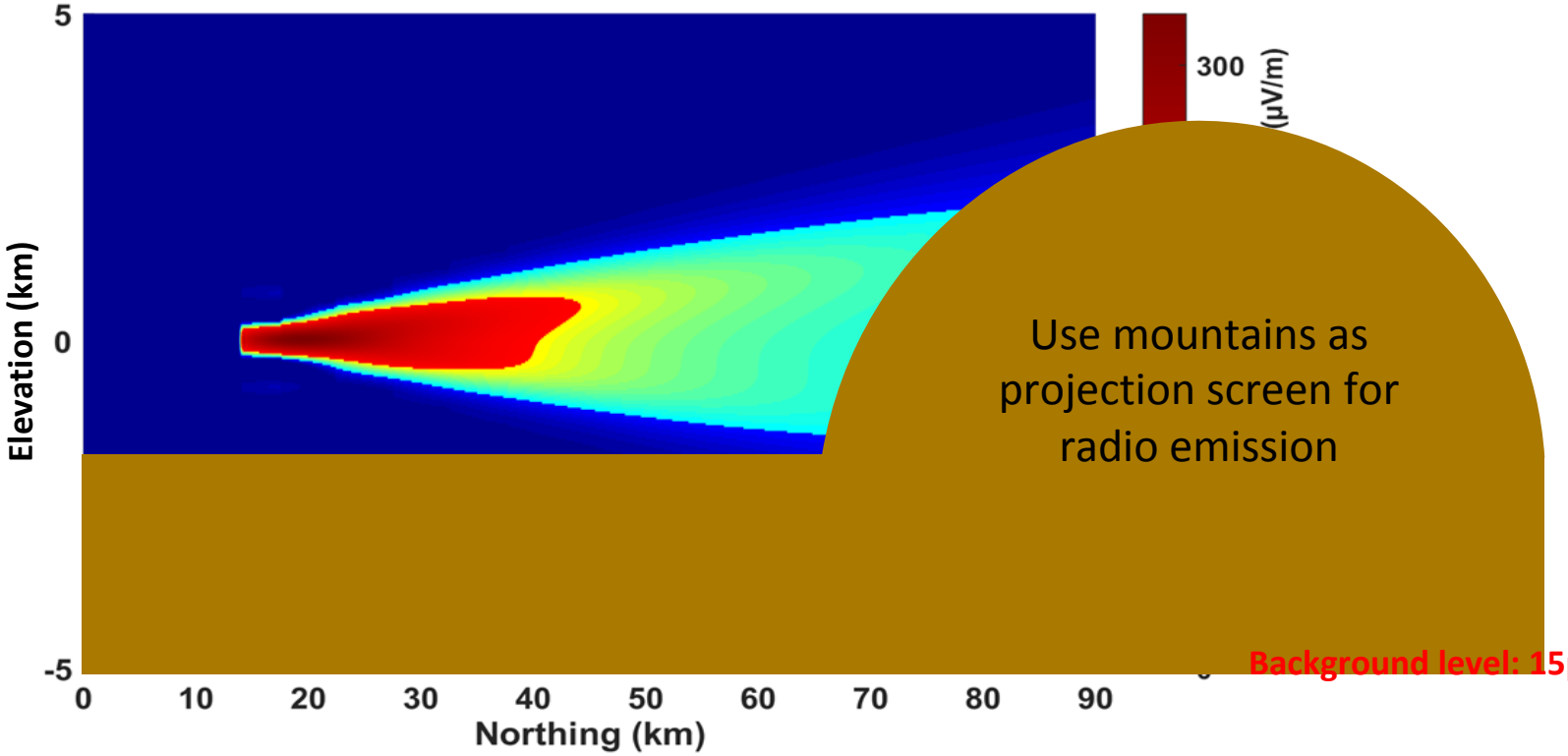


Why radio?

Because it is perfect for horizontal air showers!

50-200MHz radio emission of a $10^{17.5}$eV shower viewed from the side:

~10s of km² detectable footprint @ ~100 km!!



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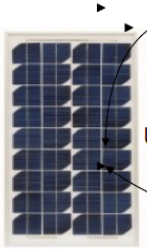
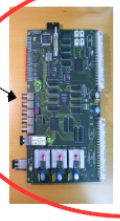
Why radio? Because it is cheap!

Toward a second generation of stations: fully based on mainstream technologies

Consumpt.<2.5 W (5V*0.5A)
WIFI/3G...
Processing
Storage > 16Go
Cost<200E



USB link



ADC
+ Trigger
+ GPS dating

Power source: 10W
(12V)
Surface 40*25cm
Cost <60E

All in radiator head

Cost objective < 800 E/station

Consumption < 5 W

Mecanics < 10 kg, no civil engineering

P. Lautridou (2011)

The GRAND project

Giant Radio Array for Neutrino Detection

Science and Design

Author list

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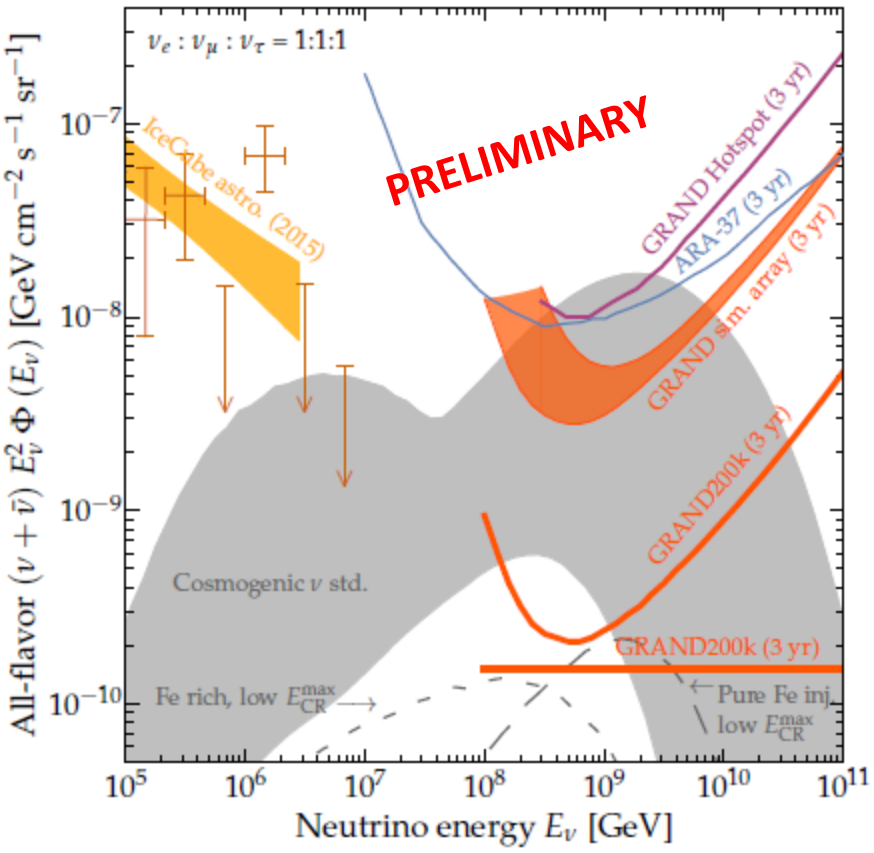
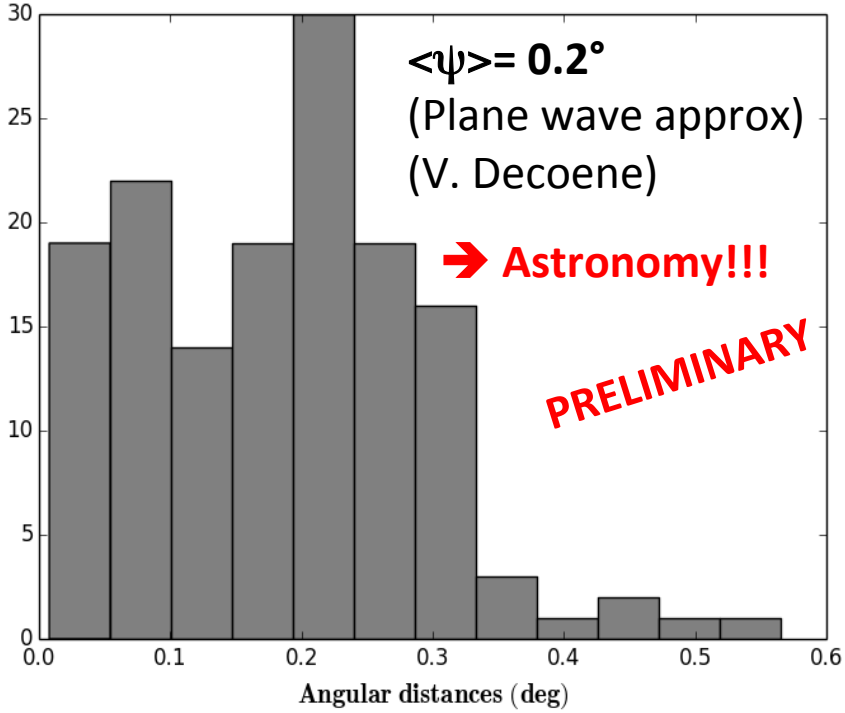
January 2018

GRAND goal

- Large enough to guarantee detection of UHE



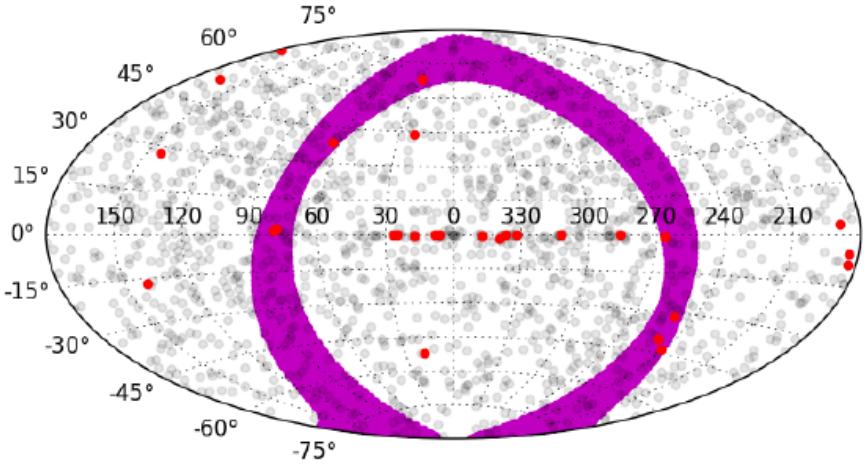


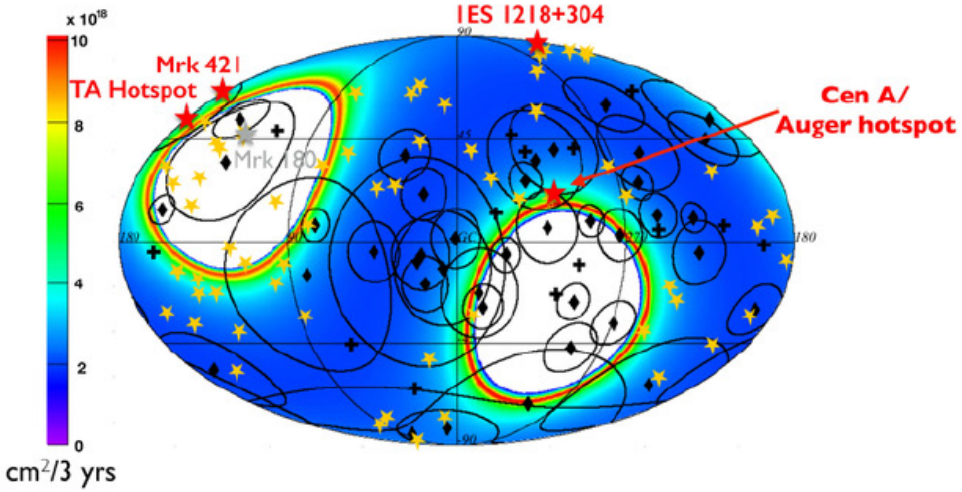
o(10-20) hotpsots of o(20-10) kAntennas deployed over o(20-10'000) km² **hotspots** with favorable topographies around the world.

➔ **total area: 200'000km²**

GRAND FoV

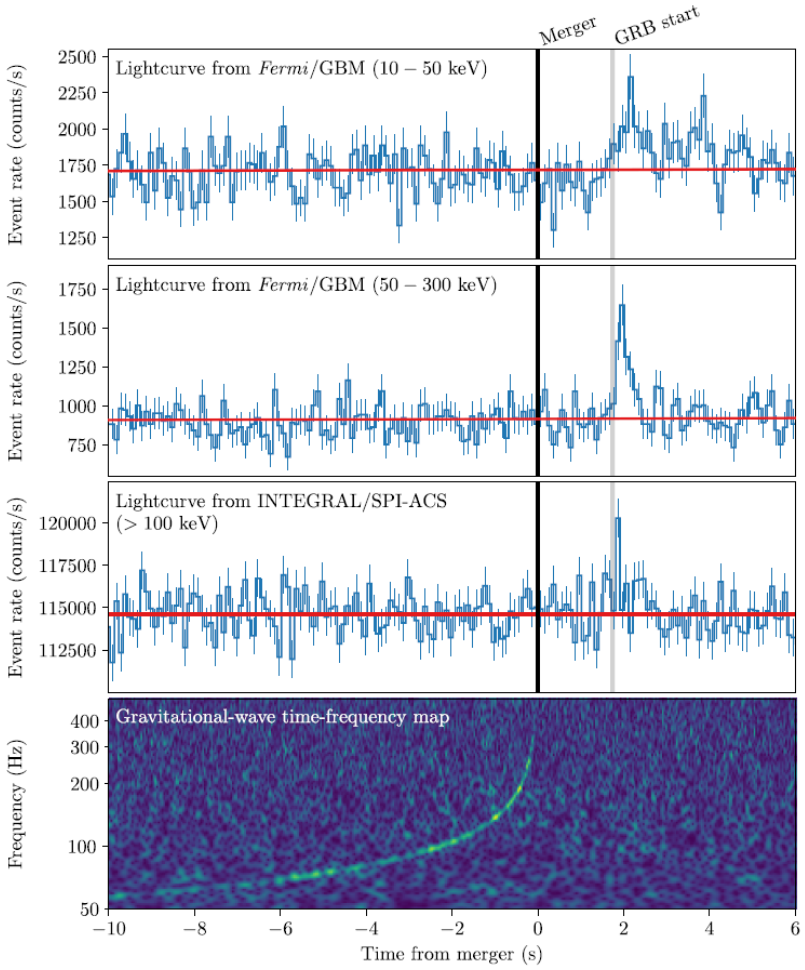
- 85<θ<95° but all azimuth ➔ large fraction of sky covered in 24h





Here computed for one single 200'000km² array located at TREND site.

GRAND aims at taking part in the MultiMessenger Astronomy Era



SEARCH FOR HIGH-ENERGY NEUTRINOS FROM BINARY NEUTRON STAR MERGER GW170817 WITH ANTARES, ICECUBE, AND THE PIERRE AUGER OBSERVATORY

A. Albert,[1] M. André,[2] M. Anghinolfi,[3] M. Ardid,[4] J.-J. Aubert,[5] J. Aublin,[6] T. Avgitas,[6] B. Baret,[6] J. Barrios-Martí,[7] S. Basa,[8] B. Belhorma,[9] V. Bertin,[5] S. Biagi,[10] R. Bormuth,[11,12] S. Bourret,[6] M.C. Bouwhuis,[11] H. Brânzaş,[13] R. Bruijn,[11,14] J. Brunner,[5] J. Busto,[5] A. Capone,[15,16] L. Caramete,[13] J. Carr,[5] S. Celli,[15,16,17] R. Cherkaoui El Moursli,[18] T. Chiarusi,[19] M. Circella,[20] J.A.B. Coelho,[6] A. Coleiro,[6,7] R. Coniglione,[10] H. Costantini,[5] P. Coyle,[5] A. Creusot,[6] A. F. Díaz,[21] A. Deschamps,[22] G. De Bonis,[15] C. Distefano,[10] I. Di Palma,[15,16] A. Domi,[3,23] C. Donzaud,[6,24] D. Dornic,[5] D. Drouhin,[1] T. Eberl,[25] I. El Bojaddaini,[26] N. El Khayati,[18] D. Elsässer,[27] A. Enzenhöfer,[5] A. Ettahiri,[18] F. Fassi,[18] I. Felis,[4] L.A. Fusco,[19,28] P. Gay,[29,6] V. Giordano,[30] H. Glotin,[31,32] T. Grégoire,[6] R. Gracia Ruiz,[6,33] K. Graf,[25] S. Hallmann,[25] H. van Haren,[34] A.J. Heijboer,[11] Y. Hello,[22] J.J. Hernández-Rey,[7] J. Hössl,[25] J. Hofestädt,[25] G. Illuminati,[7] C.W. James,[25] M. de Jong,[11,12] M. Jongen,[11] M. Kadler,[27] O. Kalekin,[25] U. Katz,[25] D. Kiessling,[25] A. Kouchner,[6,32] M. Kreter,[27] I. Kreykenbohm,[35] V. Kulikovskiy,[5,36] C. Lachaud,[6] R. Lahmann,[25] D. Lefèvre,[37] E. Leonora,[30,38] M. Lotze,[7] S. Loucatos,[39,6] M. Marcelin,[8] A. Margiotta,[19,28] A. Marinelli,[40,41] J.A. Martínez-Mora,[4] R. Mele,[42,43] K. Melis,[11,14] T. Michael,[11] P. Migliozzi,[42] A. Moussa,[26] S. Navas,[44] E. Nezri,[8] M. Organokov,[33] G.E. Păvălaş,[13] C. Pellegrino,[19,28] C. Perrina,[15,16] P. Piattelli,[10] V. Popa,[13] T. Pradier,[33] L. Quinn,[5] C. Racca,[1] G. Riccobene,[10] A. Sánchez-Losa,[20] M. Saldaña,[4] I. Salvadori,[5] D. F. E. Samtleben,[11,12] M. Sanguineti,[3,23] P. Sapienza,[10] F. Schüssler,[39] C. Sieger,[25] M. Spurio,[19,28] Th. Stolarczyk,[39] M. Taiuti,[3,23] Y. Tayalati,[18] A. Trovato,[10] D. Turpin,[5] C. Tönnis,[7] B. Vallage,[39,6] V. Van Elewyck,[6,32] F. Versari,[19,28] D. Vivolo,[42,43] A. Vizzoca,[15,16] J. Wilms,[45] J.D. Zornoza,[7] and J. Zúñiga[7]

(ANTARES Collaboration)

M. G. Aartsen,[46] M. Ackermann,[47] J. Adams,[48] J. A. Aguilar,[49] M. Ahlers,[50] M. Ahrens,[51] I. Al Samarai,[52]

More generaly:
France wide variety of experimental projects
IS a strength… and should be presented as such!

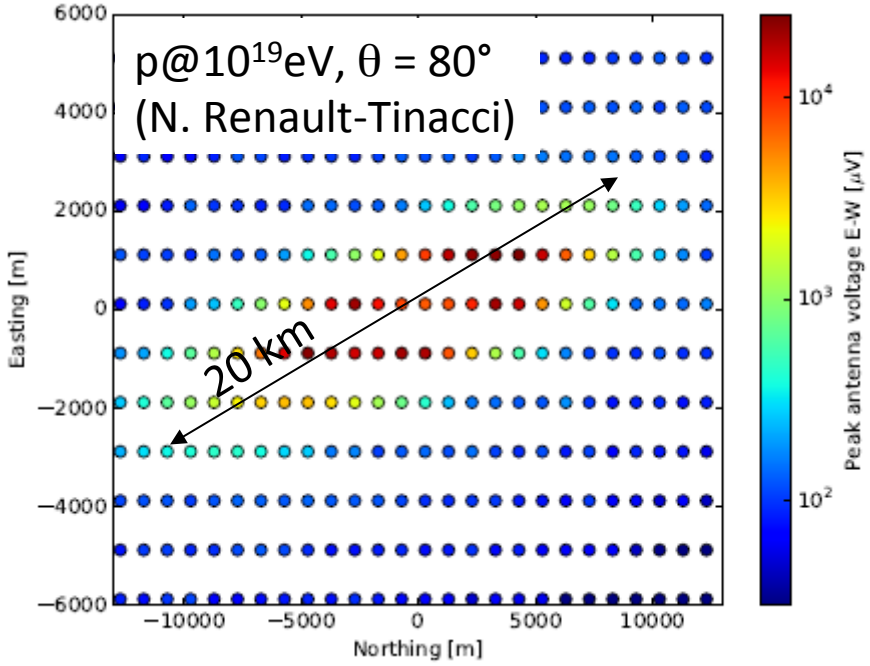
GRAND & CRs

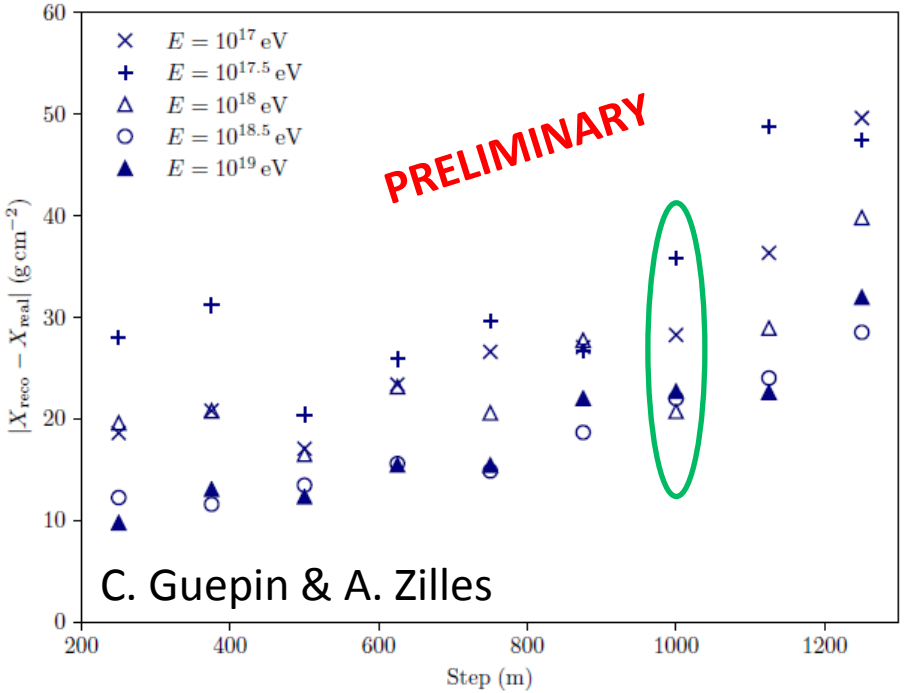
- Very large footprint for inclined air showers

➔ good detection efficiency & good X_{max} resolution (20g/cm²?)

➔ Precision + stat (aperture ~ 15x AUGER)@highest energies

➔ **Great tool for UHECRs & UHE γ**



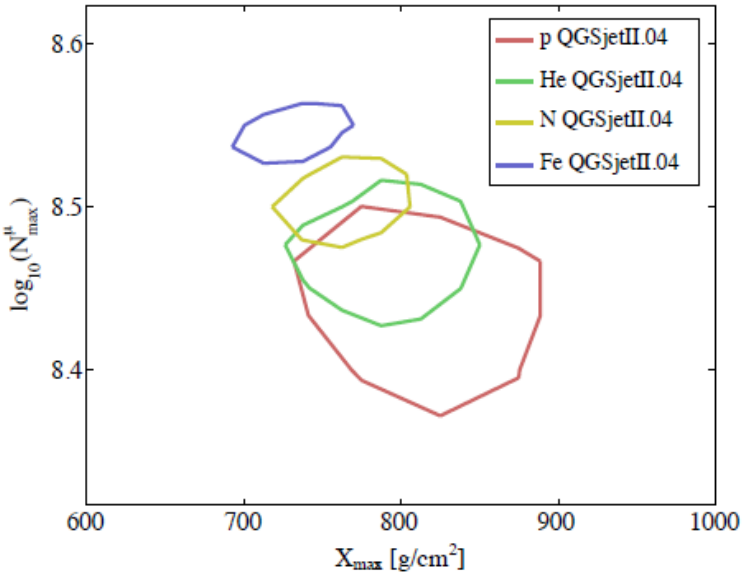


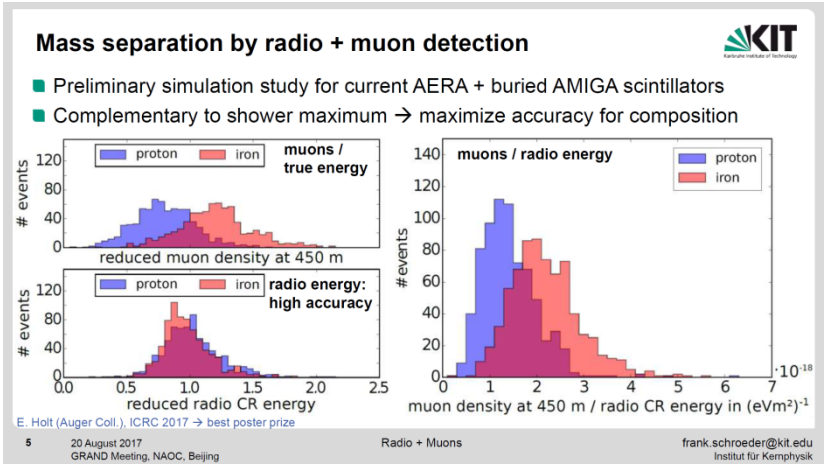
GRAND in practice

- Huge technical challenge: Trigger? Data collection? Reconstruction of ~horizontal showers? Background rejection?
- Need for:
  - time (full array not before 2030) to develop a staged approach.
  - Important step: an engeneering array with dedicated design ➔ **GRANDproto300:** 300 antennas over ~150km²

GRANDproto300

- 300 antennas, half with 200m step, half with 1km step
- GRAND antennas + dedicated electronics (*a la AERA*), with bullet WiFi data transfer.
- Site: XinJiang. **Funding secured. Expected start date: 2020**.
- Goal:
  - Demonstrate identification & reconstruction of inclined CR-induced air showers (2020-1)
  - Develop, optimise and validate trigger+data transfer strategies (2022+
  - **Physics program as well:** study of Gal-Extragal CR origin transition <u>when complemented by surface array</u> (stat: 10s of kEvents/year above 10^17eV).





Conclusion

- UHE neutrino as a natural & powerfull tool for multimessenger study of violent phenomena in the Universe.
- Several projects in early development stages. Nothing to be expected before mid-2020's.
- GRAND aiming at gigantic antenna network. First stage = 300km² engineering array, allowing for CR physics @ Gal-Extragal transition