UHE cosmic neutrinos radio-detection (and TREND)

MACROS, Paris – November 29, 2013

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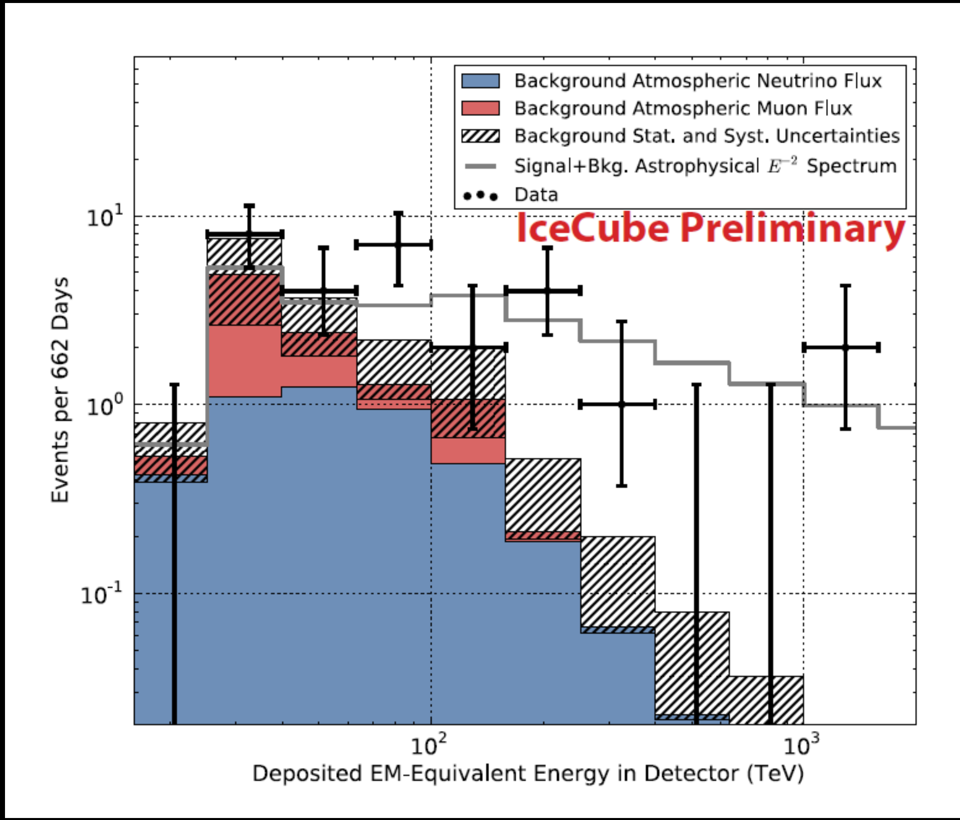
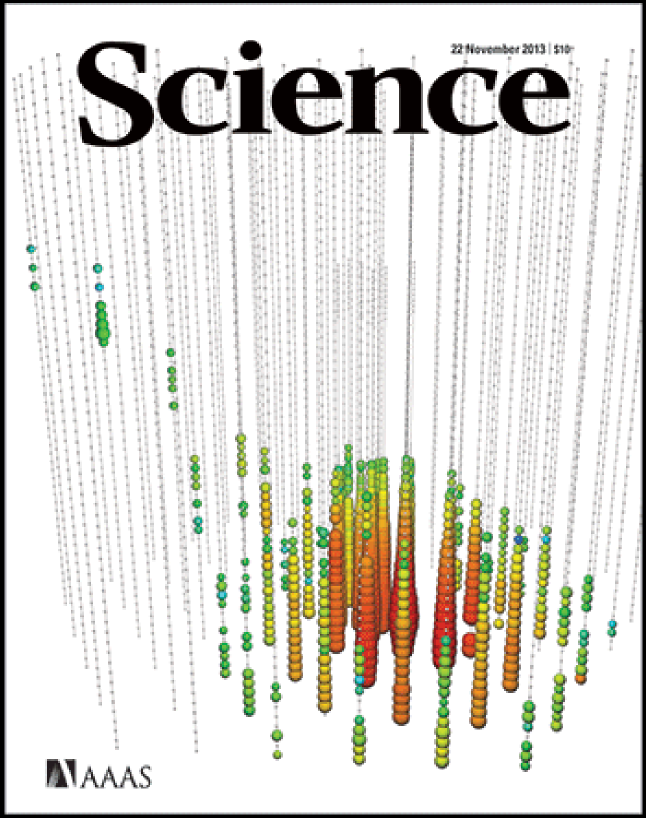
LPNHE Paris &NAOC Beijing

Birth of neutrino astronomy

- IceCube 2012&2013
  - Milestone in astronomy&astrophysics but:
  - Angular reconstruction for shower events ?
  - ~1 event/year above 250TeV.





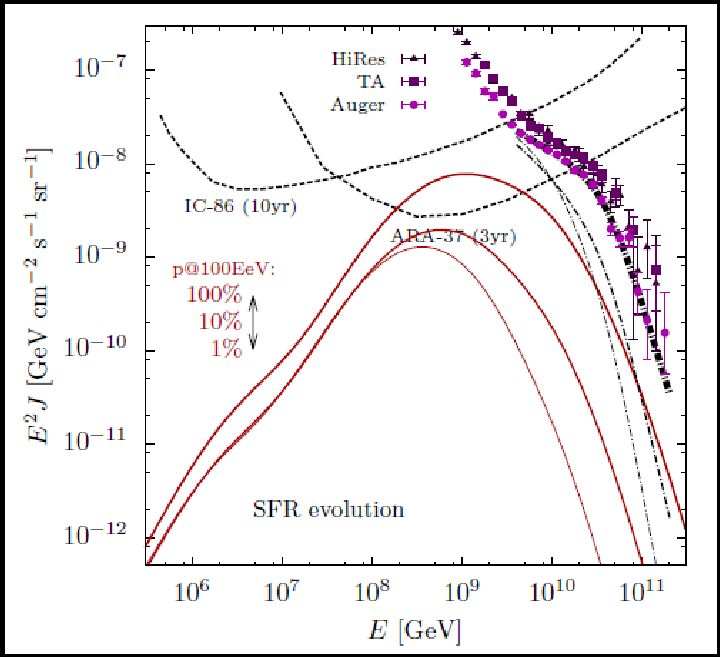
Physics with UHE cosmic neutrinos

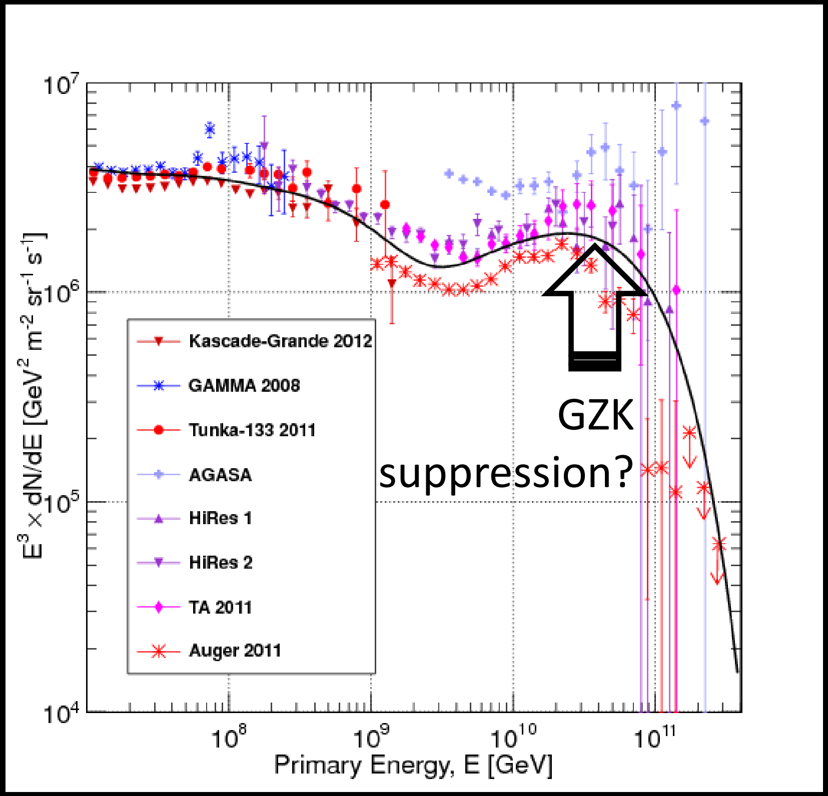
- GZK neutrinos

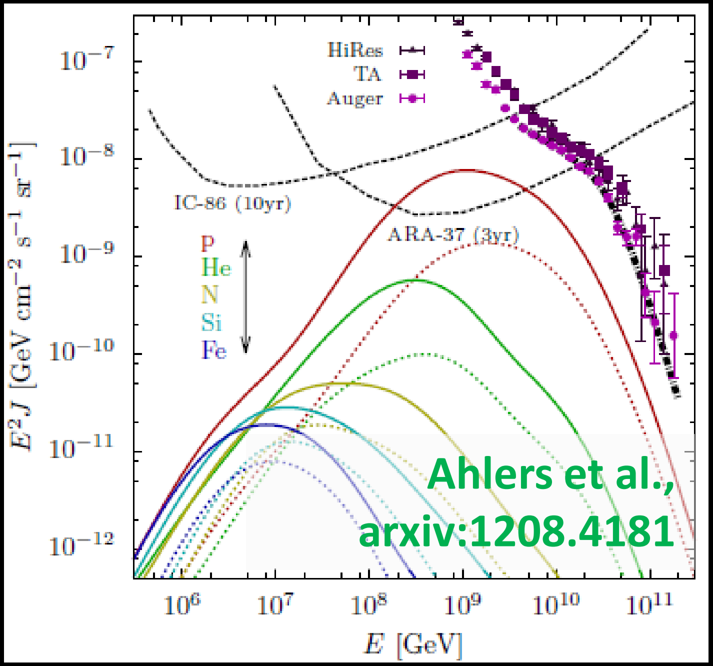
$p+\gamma_{CMB} \longrightarrow \Delta^{+} \longrightarrow \pi^{+} + n.$

$\pi^{+} \longrightarrow l + \nu_{l}.$

Great tool to study UHECRs.

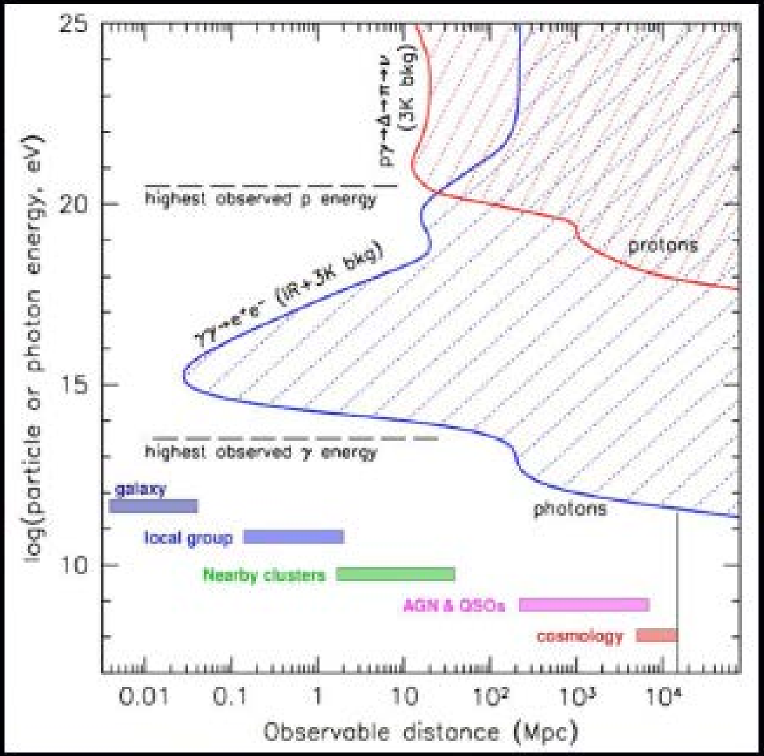






Physics with UHE cosmic neutrinos

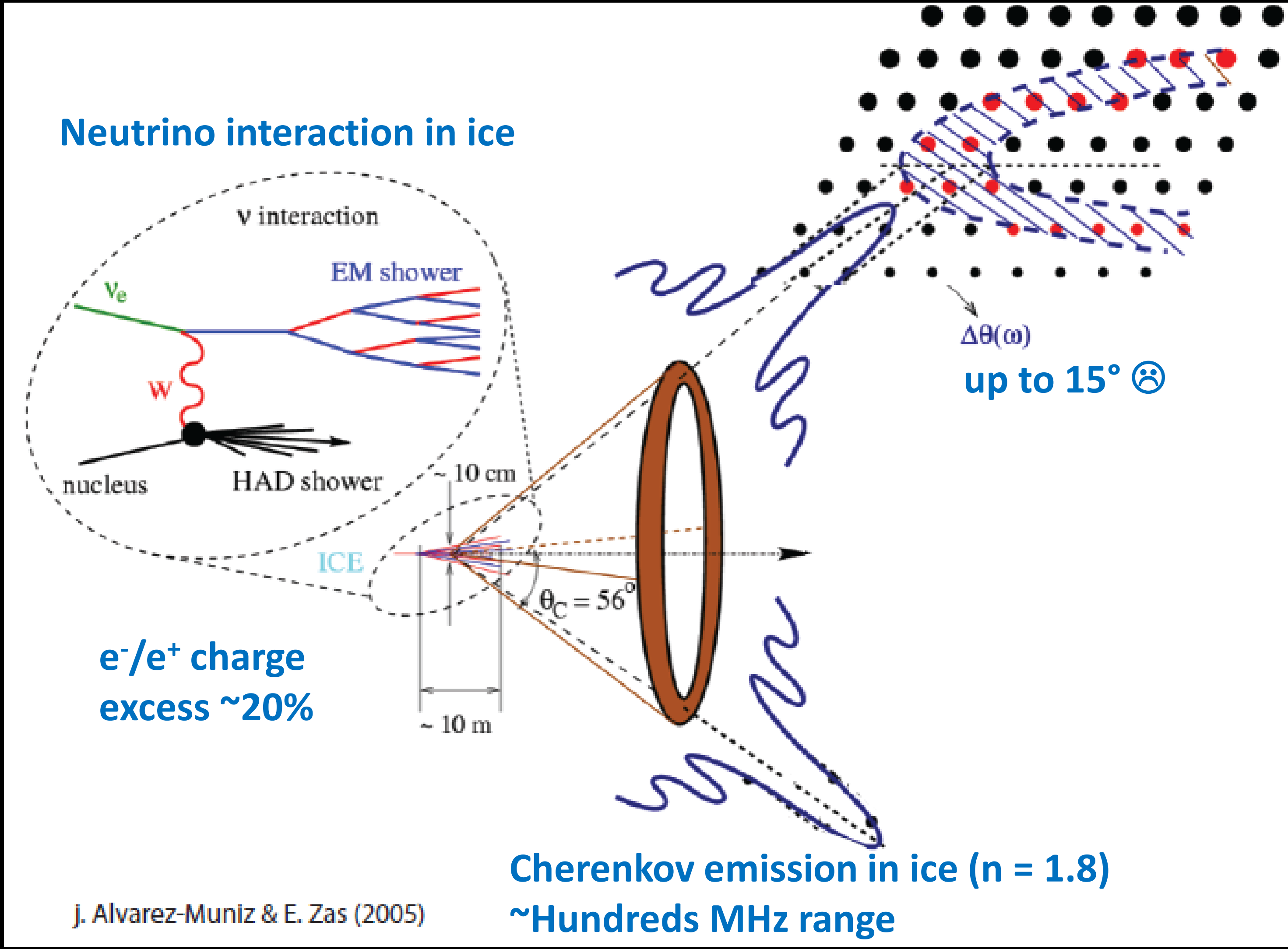
- Lots of physics with neutrinos above 10^{16}eV
  - Test of UHECRs sources AGN, GRBS…
  - Probe distant Universe
  - …
- Downside: neutrino detection challenge + low flux @ UHE…



Need for cheap / scalable /easily maintainable detector.

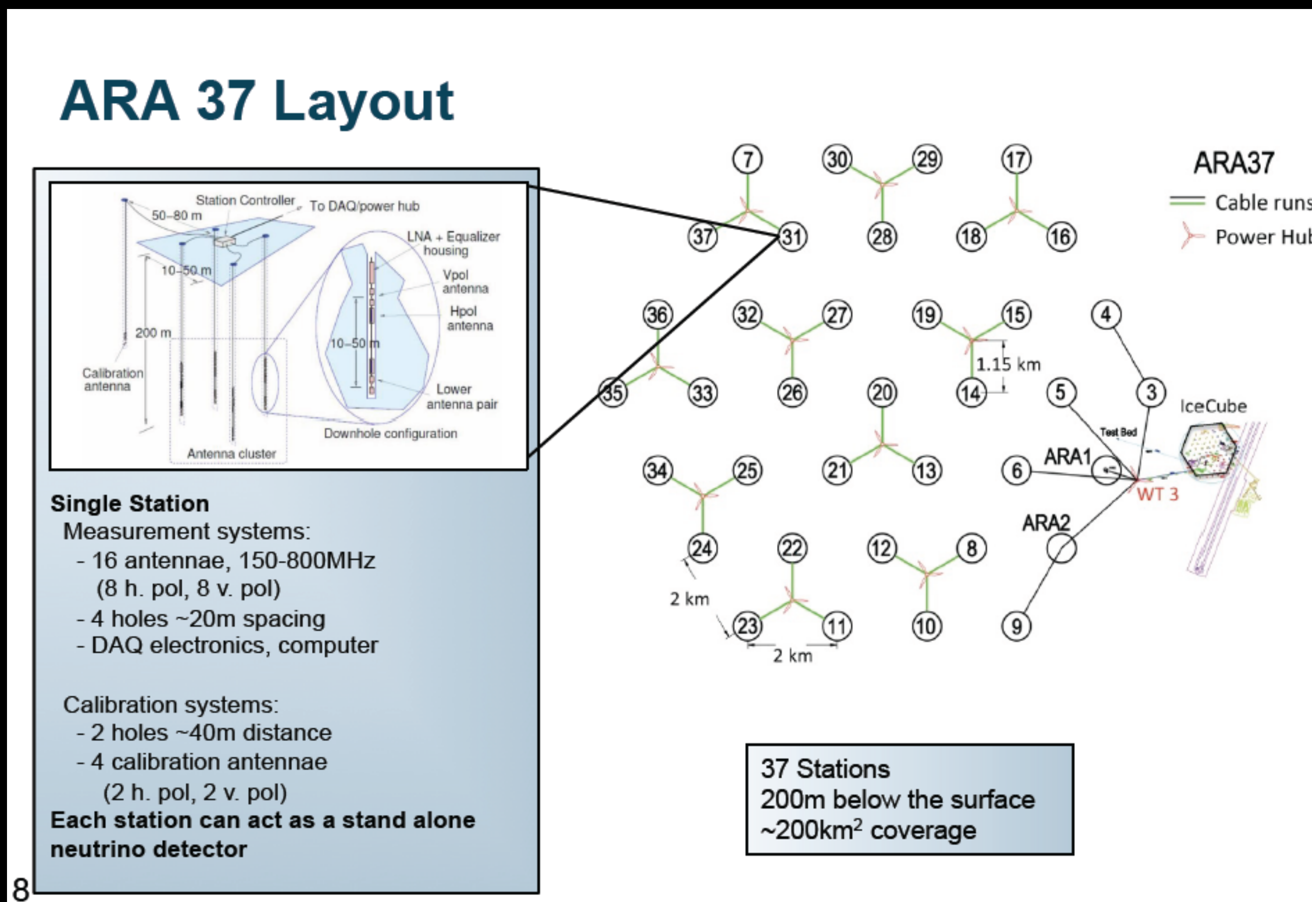
… Radio?

Askaryan effect in ice



Radio in Antartica

- Askaryan Radio Array (ARA)

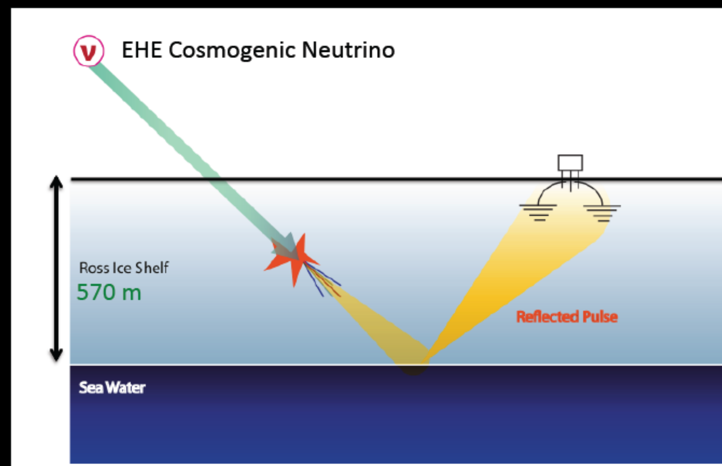


37 stations with 2x4 antennas each, 200m deep in ice.
Full array of 200km² could be deployed in 5 years on a site neighbouring IceCube.

Jonathan Davies ICRC2013

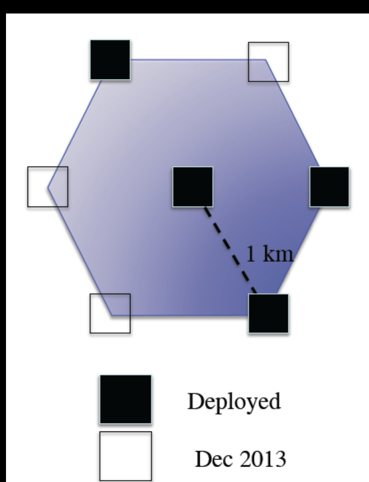
Radio in Antartica

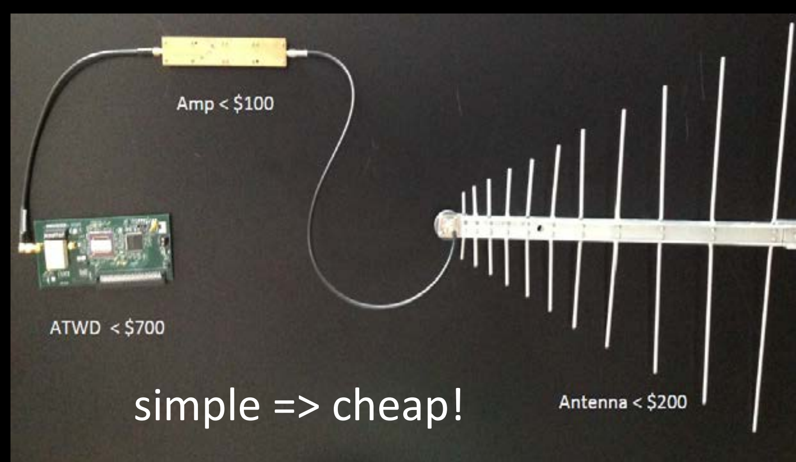
- ARIANNA



Reflection of ν-induced radio waves at bottom of ice shelf.
(☹ : ice interfaces reflexions effects)

Prototype data (4 stations)
90 live days, no candidate



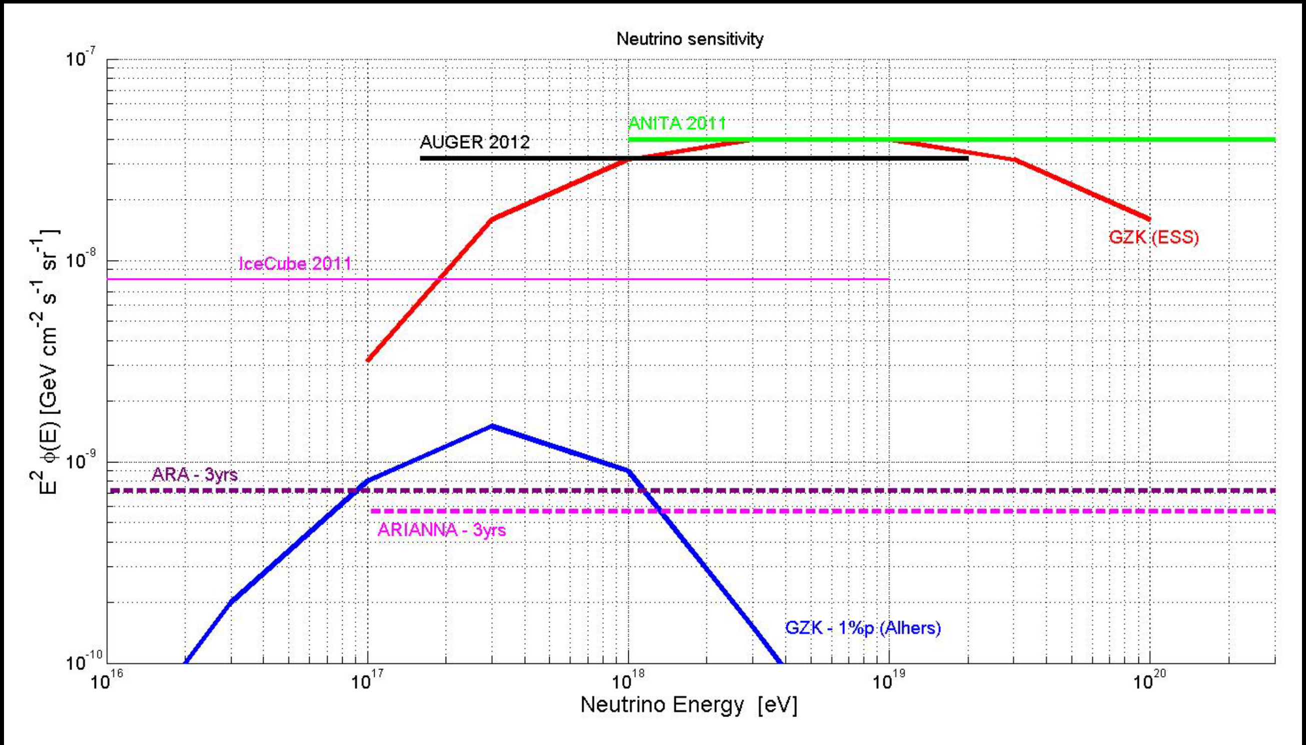


Aiming at 960 stations over 31×31 km^2 in 5 years

Joulien Tatar
Talk @CPPM, IN2P3
June 2013

Radio in Antartica

- Expected sensitivity



ARA & ARIANA expect o(10-30) events/year for a GZK-ESS neutrino flux.

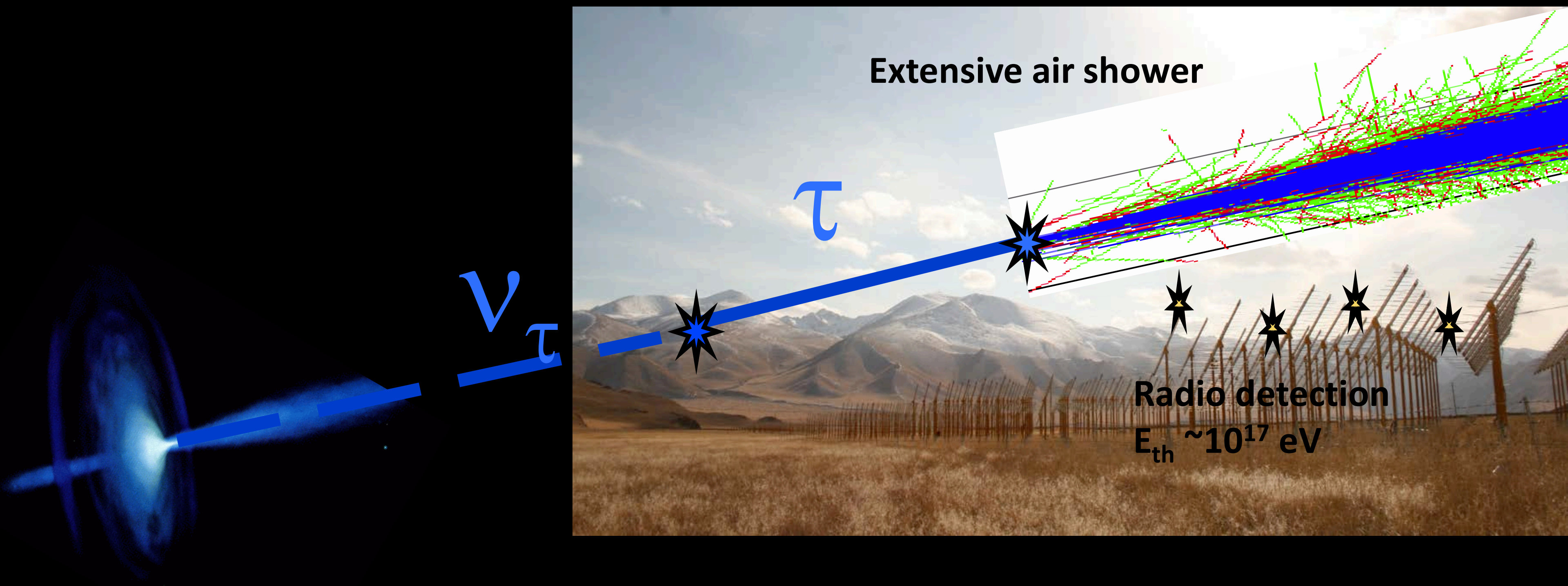
Antarctica projects:

+: low background (… what about EAS or HE muons?)

-: remote site: deployment, maintenance and price.

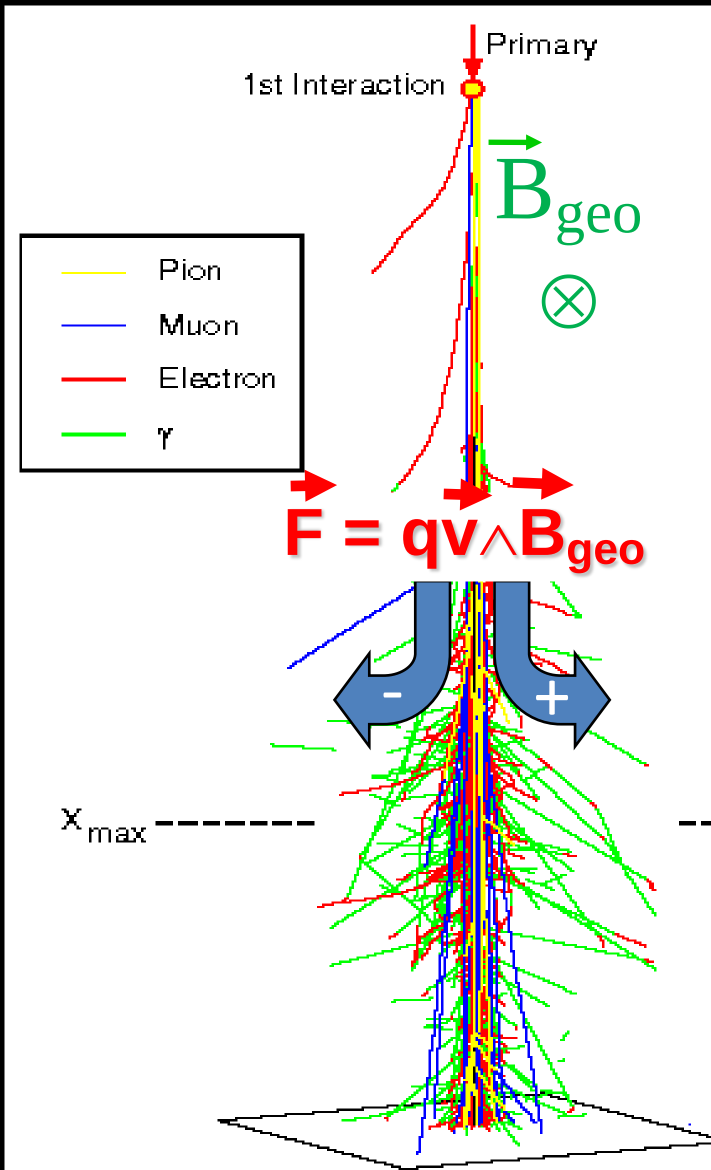
Worth to try something different!

Neutrino-induced EAS

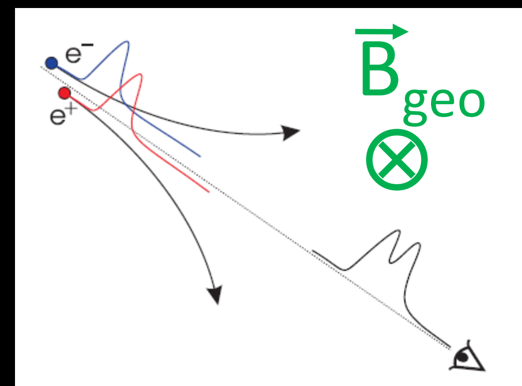


- Earth + mountains as target for neutrino interaction (AUGER-type)
- Radio detection of subsequent EAS (good at large zenith angles)

EAS radiodetection: principle

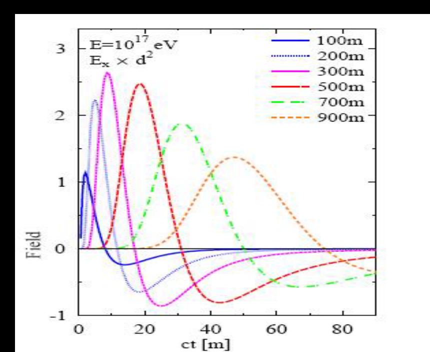


- Dominant effect: acceleration of relativistic charged particles in the Earth magnetic field (Kahn & Lerche, 1965): **geosynchrotron emission**



- **Coherent** effect

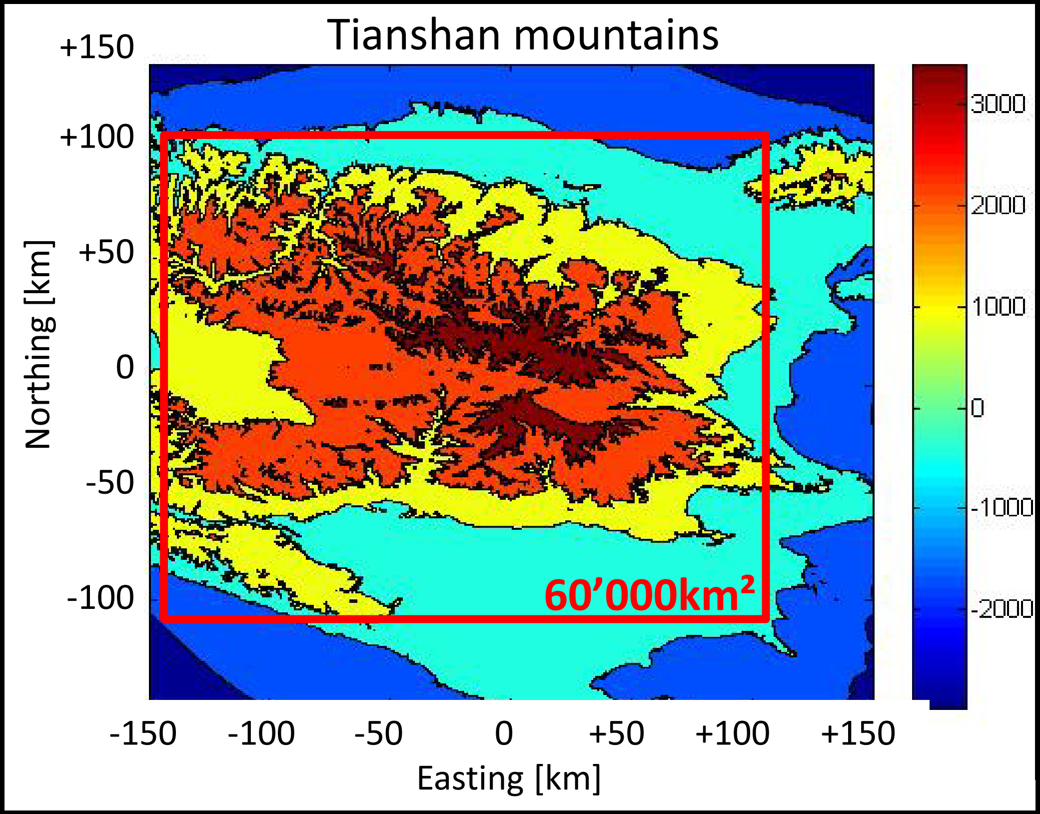
  detectable radio emission. Tens MHz range (transients <100ns & 10s μV/m)



- **Detection of EAS radio signals:**
  Haverah Park (1971)
  LOPES & CODALEMA (2005)

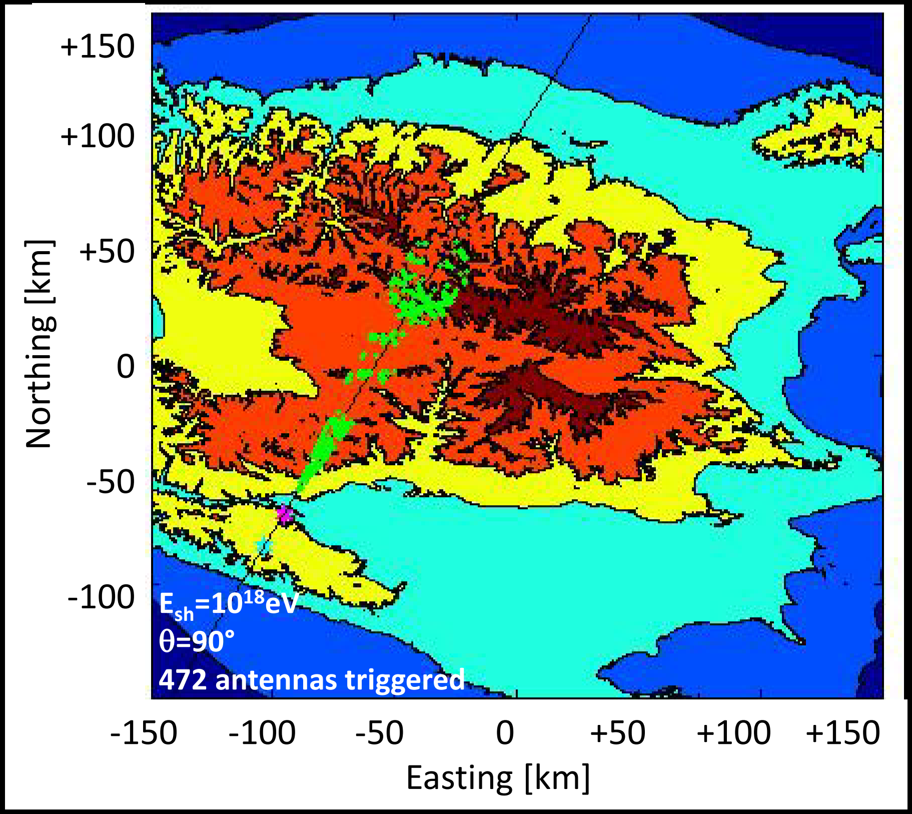
GRAND:
a Giant Radio Antenna Neutrino Detector

- Proposal: a HUGE (several 10’000km²) array of (very basic) radio antennas (~100k antennas for 800m step square grid)
- deployed over (radio-quiet) mountain area (e.g. Tianshan)



GRAND

- On-going MC study of detector sensitivity
- All tools integrated (or developped) and tested.
- Massive simulation production on-going (already completed down to tau decay)

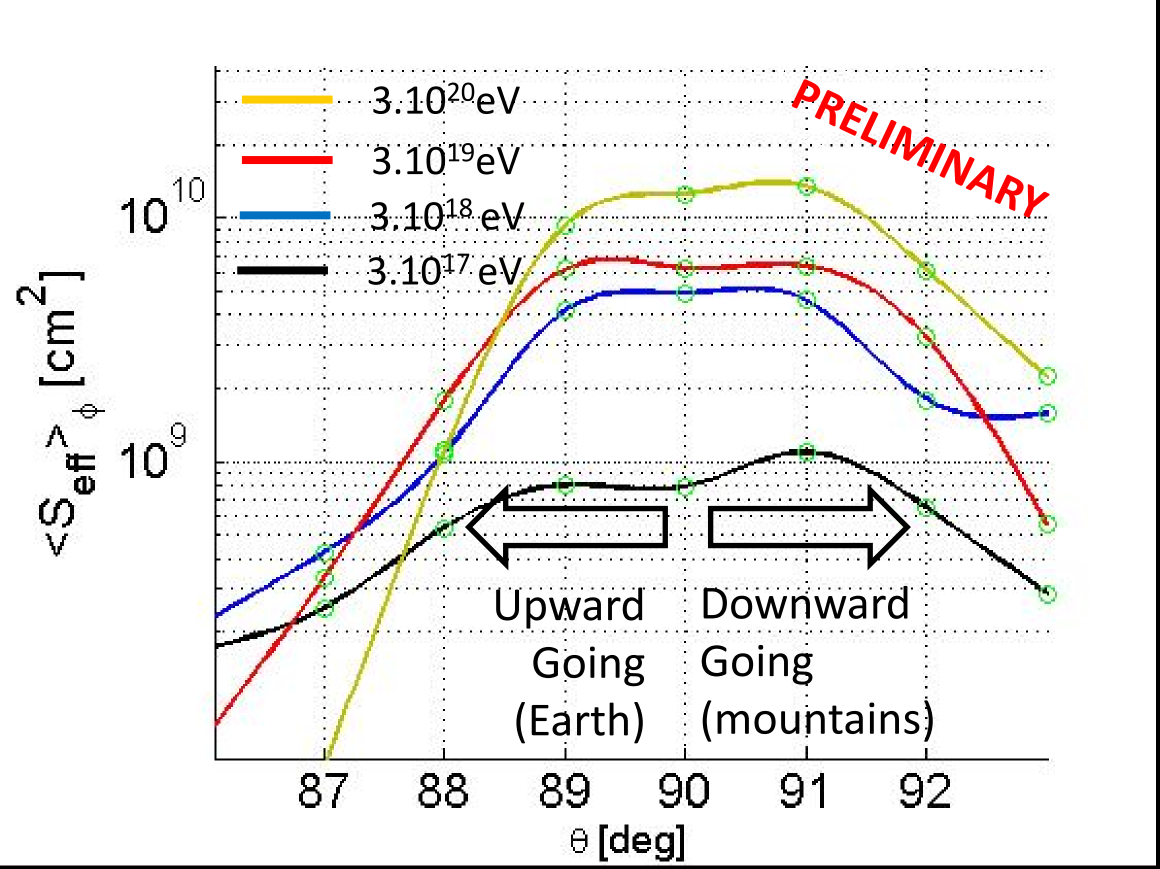


Preliminary estimate of GRAND neutrino sensitivity

with
geometric modelisation of radio emission:
- Emission cone of 3°+ f(E)
- No signal attenuation

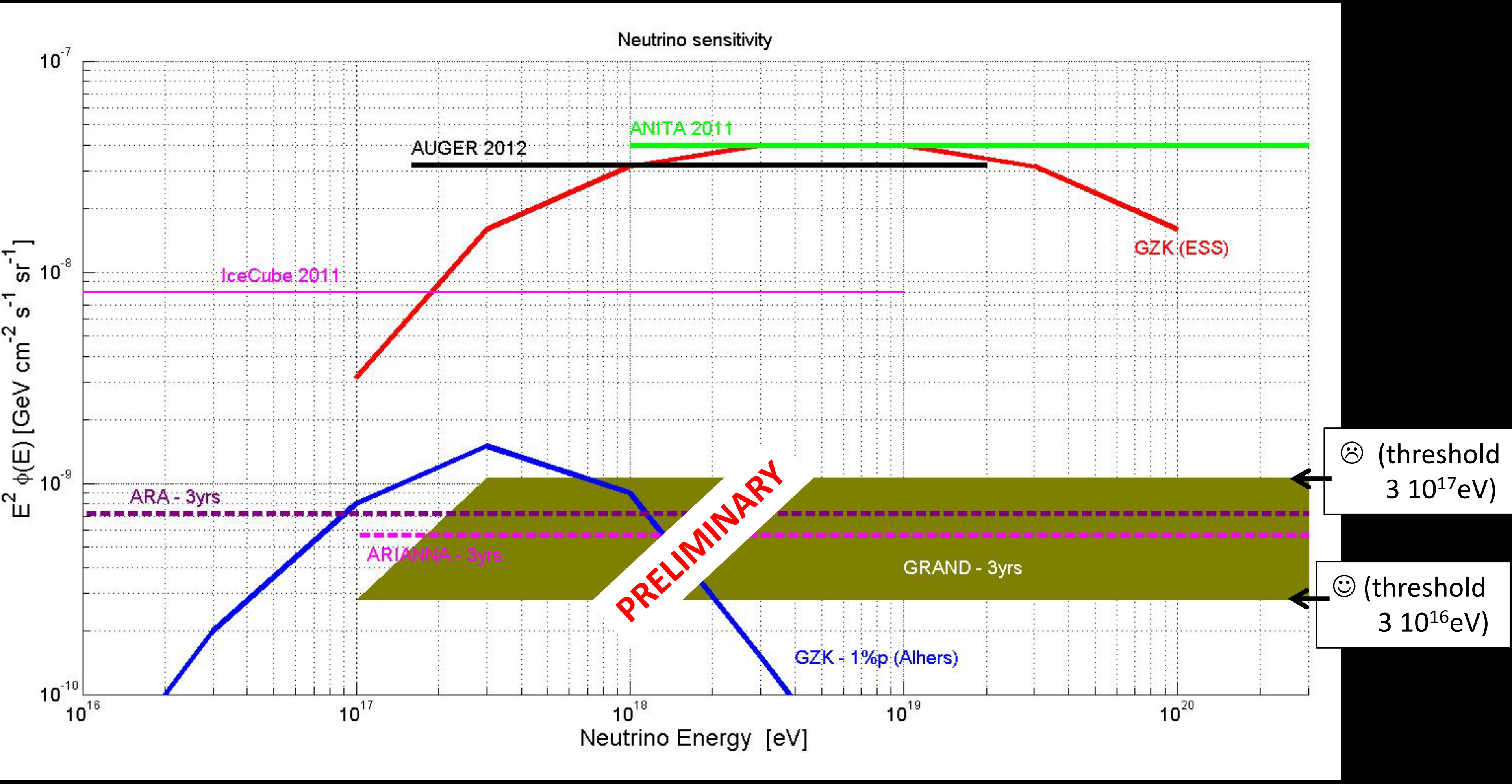
Shower assumed detected if:
- $E_{sh}>10^{17}$eV
- Cluster of 5+ antennas inside light cone & 5+km away from tau decay point.

Simulation results



- ~ Horizontal trajectories.
- Mountains are sizable tragets.
- Many extended tracks (<mult> = 190 antennas).
- Great angular resolution: $\Delta\theta<0.1°$ (assuming Δt~1ns)

GRAND sensitivity



GRAND could reach similar (up to 2x better) sensitivity compared to Antartica projects.
Angular resolution better than 0.1°.

To be confirmed/optimized with full MC.

GRAND background rejection

- Key issue: background
  - Physics background:
    - HE muons through mountains
    - Inclined EAS (badly) reconstructed below horizon

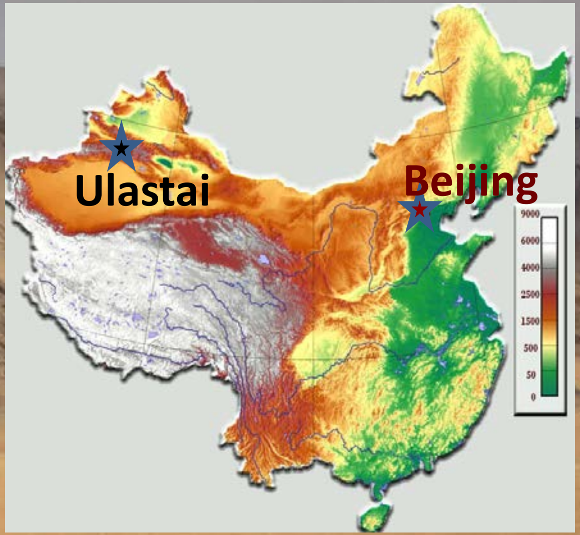
Decay length: $L = E_{\mu}$ (PeV) x 6.5 10^9 m…
Will be included in simulations.

Cutting all events reconstructed from zenith down to 1° below horizon kills this background and affects marginelly sensitivity.

  - Electromagnetic background
    - Thunderstorms, human activities, …
    - ☺ Signature is different from EAS:
      - Wavefront & amplitude pattern
      - Polarization
    - ☹ Rate is HUGE… even in remote areas

Radio background rejection: on-going efforts by TREND

- **Tianshan Radio Experiment for Neutrino Detection**



- Initiated in 2008 between China (Wu XiangPing NAOC, Hu HongBo IHEP) & France (OMH & Pascal Lautridou IN2P3). Today 2 French + 4 Chinese.
- Initial goal: perform **autonomous radio-detection of EAS** on the site of the 21CMA radio-interferometer **(**do not bother about acceptance, energy estimation or composition study)
- 6(2009)->15(2010)->50(2011) antennas deployed.

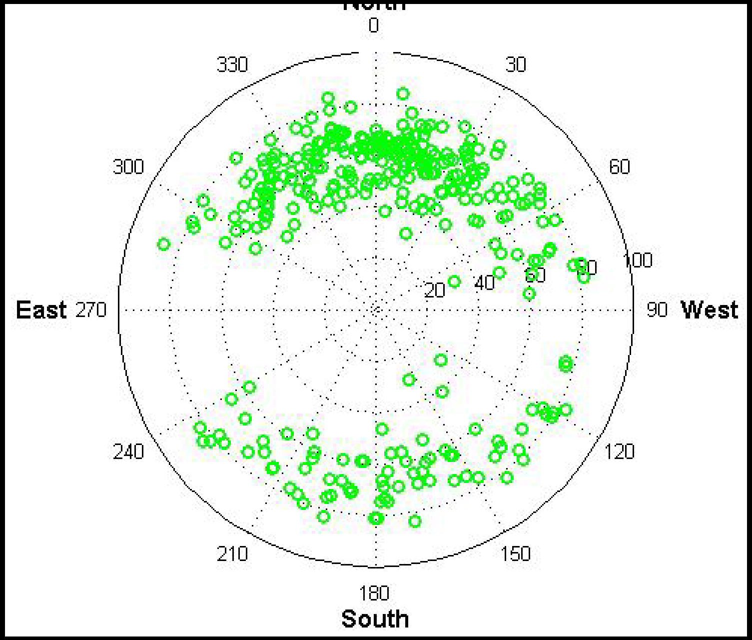
TREND-50 results

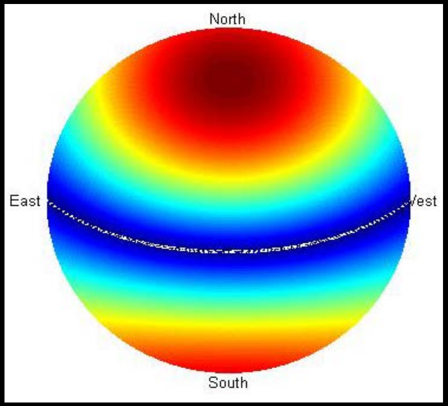
- 2010: some EAS radio candidates (selected with dedicated algorithm) with independant detection by 3-scintilators ground array. Confirms EAS nature of these candidates.

Ardouin et al, the TREND collab, Astropart Phys 34 (2011)

- 2012: analysis of 320 live days with E-W polar.

323 EAS radio candidates selected.



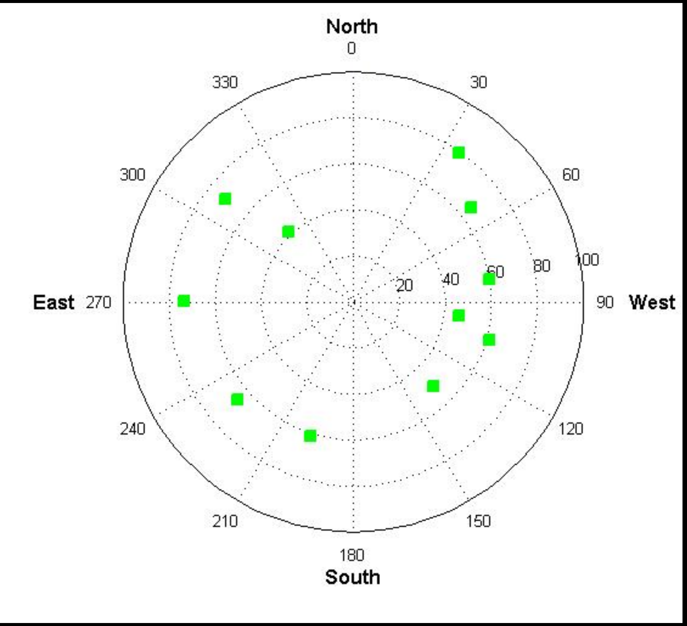


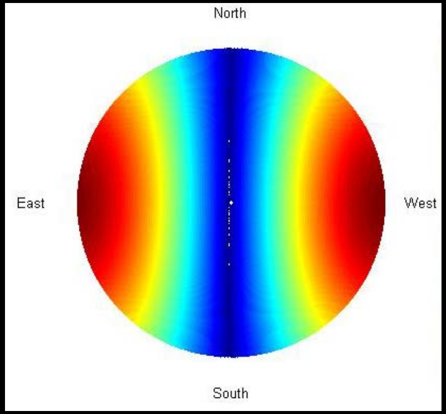
Geosynchrotron intensity map
(analytical treatment)

Arrival direction distribution follows what is expected from EAS events.
(to be confirmed with MC simulation… in progress)

TREND-50 results

- 2013: antennas rotated to N-S polar.
- Analysis of 3 months of data: 11 candidates. So far so good. Full dataset (+6 months) needed for final confirmation.





Confident that autonomous radio-detection of standard EAS is possible with limited background contamination.

Polarization measurement

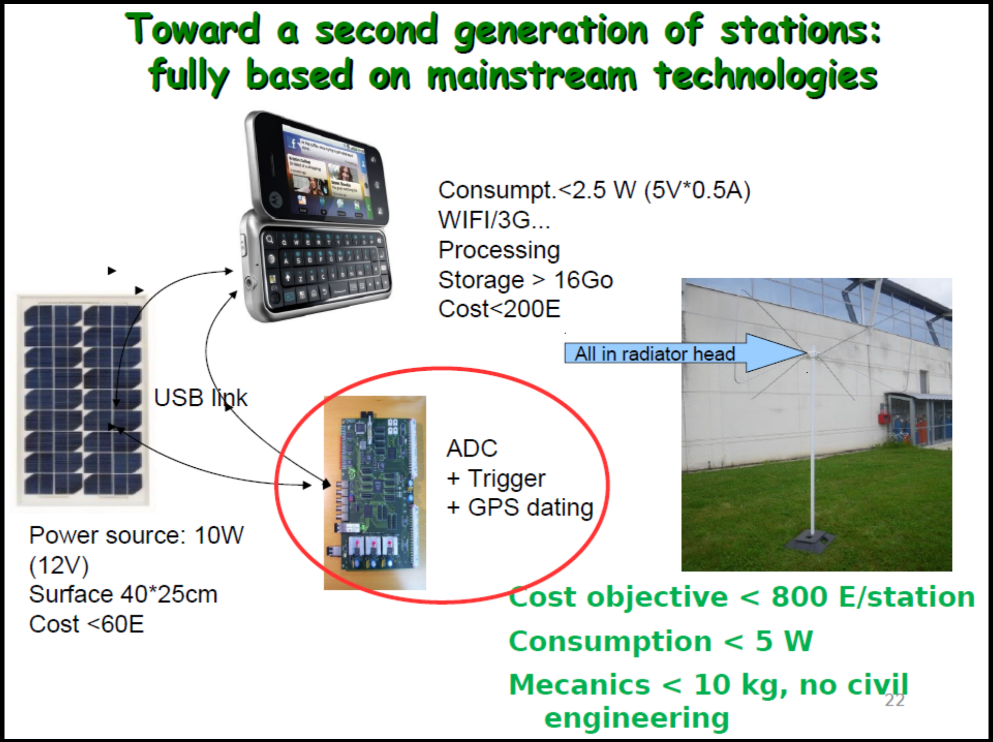
- Neutrino showers vs standard EAS:
  rate much lower & ~horizontal trajectories.

  ⇨ Need a stronger discrimination parameter: **polarization** could be the key(?)

- Hybrid setup:
  - 35 antennas with **3-polar measurement** (design with SUBATECH/CODALEMA)
  - 20 scintillators => quantitative study of bckgrd rejection.
  - First antenna tests in January 2014. Deployment of radio array to be completed within a year.
  - Setup to be used as a testbench for development of giant array detection unit.

A 100kAntennas array ?

- Manageable if minimal amount of info delivered by antenna
  (16 bits per trigger, T0: 1kHz/antenna, T1: <1Hz/antenna => 200kB/s)
- Affordable if unit price < 500 €.



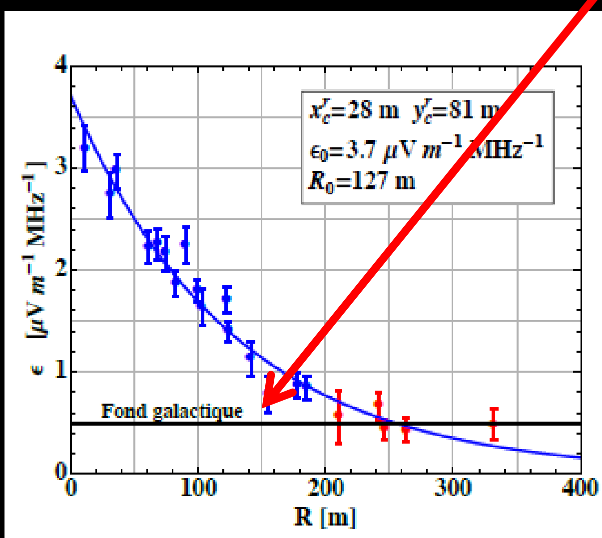
P. Lautridou 2011

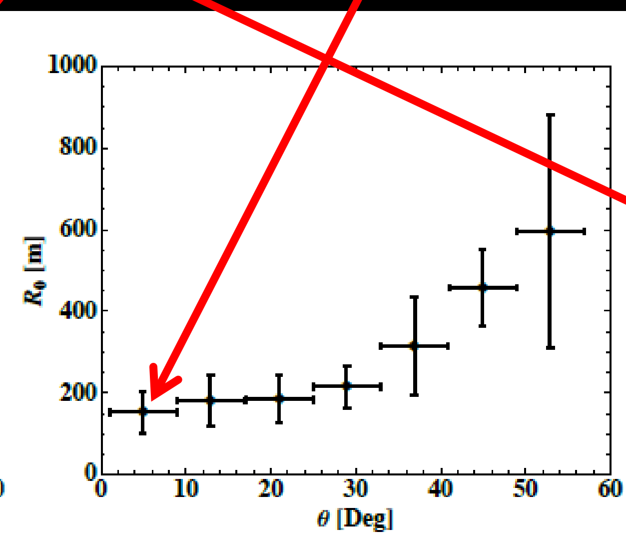
How far can we see EAS radio signals?

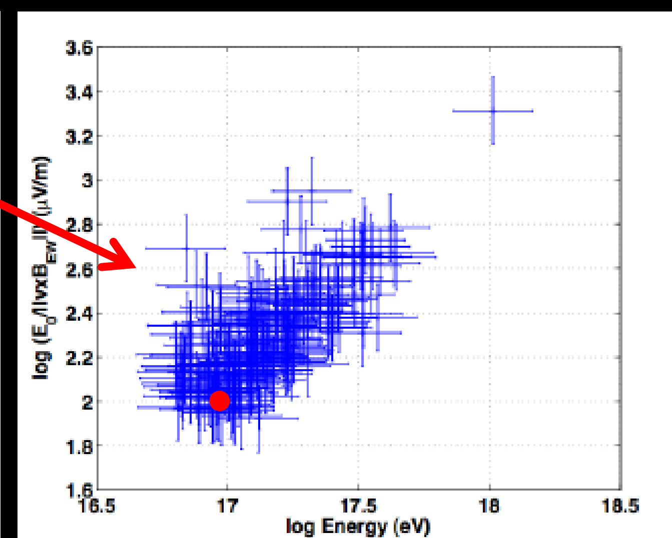
- Radio detection ultimate threshold: 0.5μV/m/MHz (Galactic noise)
- Lateral distribution: $\varepsilon=\varepsilon_0\exp(-d/d_0)$ with d_0~200m (or more)
- ε_0 scales linearly with E after correction for geomagn. angle (data & simu) and 10^{17}eV ⇔ 0-2 μV/m/MHz (let's take 1 on average).

$$\epsilon(\mu V m^{-1} MHz^{-1}) = \frac{E}{10^{17}eV}\exp\left(-\frac{d(m)}{200}\right) > 0.5$$

necessary for detection







CODALEMA data, *V. Marin PhD (2013 SUBATECH)*

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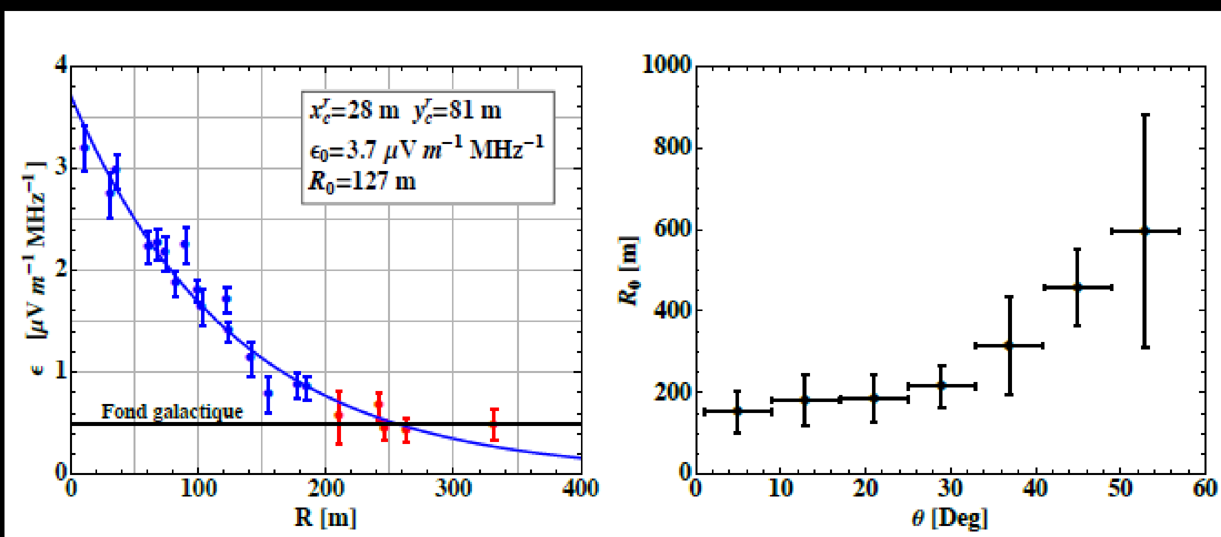
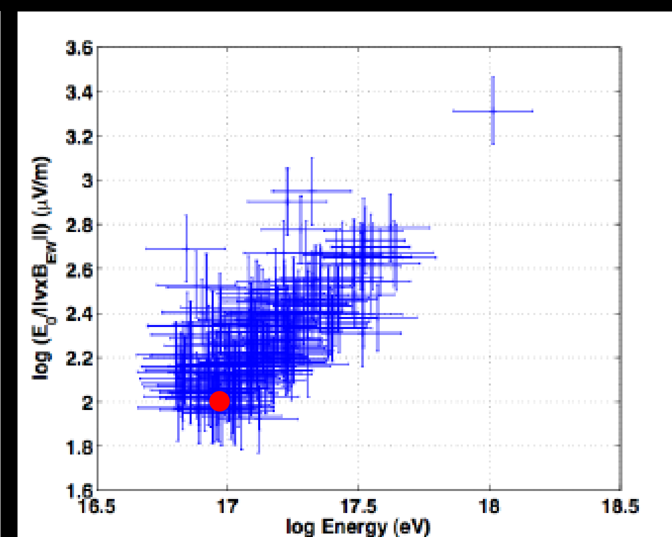




CODALEMA data, *V. Marin PhD (2013 SUBATECH)*

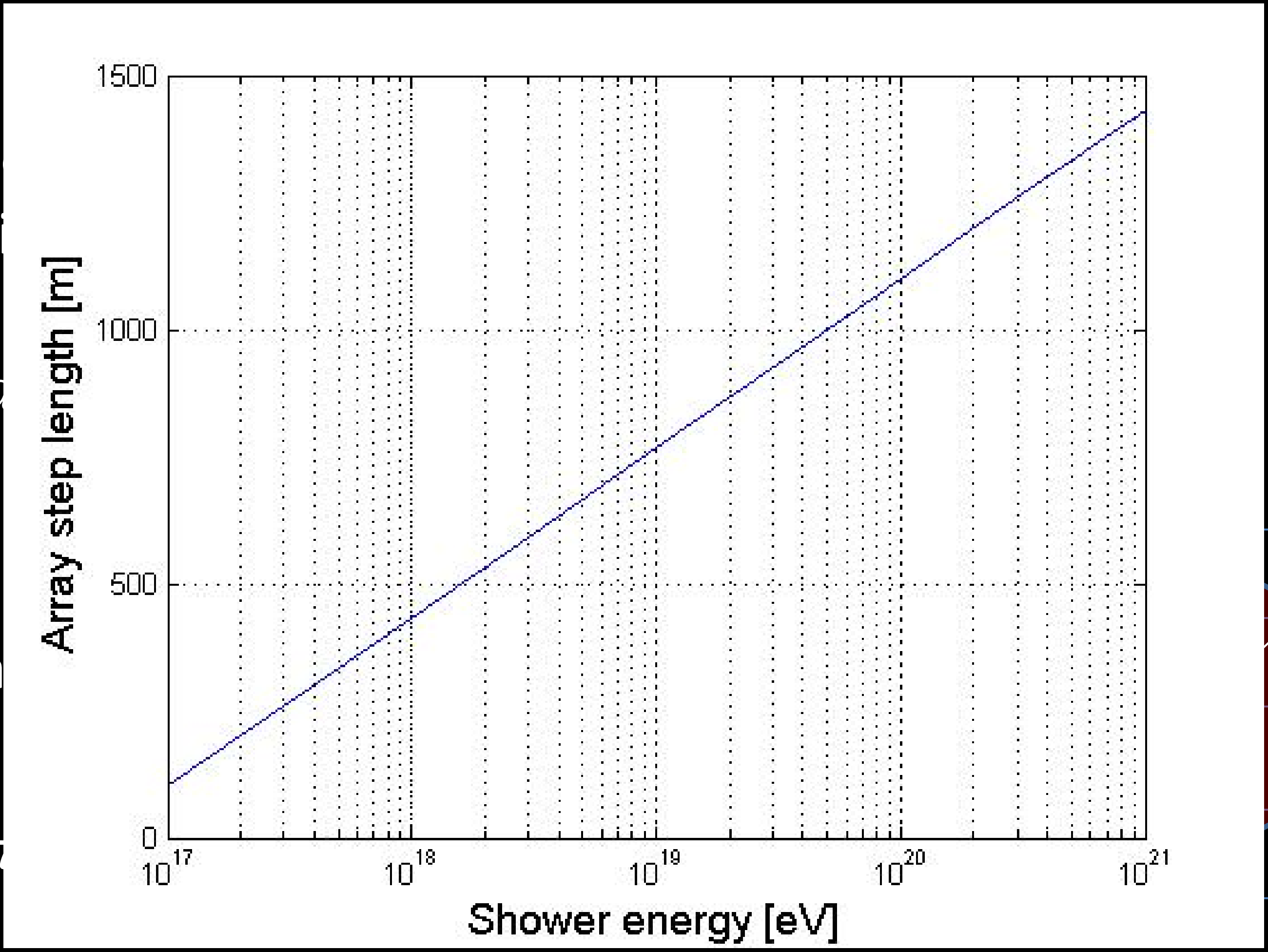
How far can we see EAS radio signals?

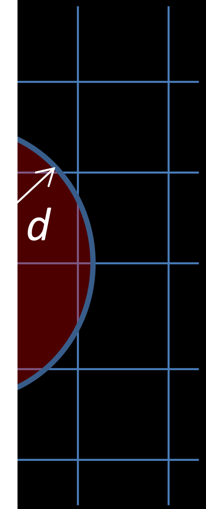
- Inversi
  detecti

a

- To get
  need a

$6a^2 < \pi$





a = 750m OK for E>10^{19} eV (1000m for E>$10^{19,5}$ eV).
Conservative estimate!!! (6+ antennas, θ=0° & d_0=200m)
4 x denser than present AUGER array… but loads more cheaper & easier!

Summary

- Plenty of physics possible with cosmic neutrinos above 10^{16}eV.
- Radio appears (at present) as the most adapted technics for their detection.
- Projects in Antartica ice, but standard earth may be a compatitive target!
- Background rejection as the key issue for such 'continental' projects.
- TREND showing that autonomous detection is possible with reduced contamination. Will check in the next 2-3 years if ~0% contamination is achievable.

<u>Last advices:</u>

- Join TREND! We need you!
- Go work in China! You'll be most welcome! A great experience… Sun rises in the East!