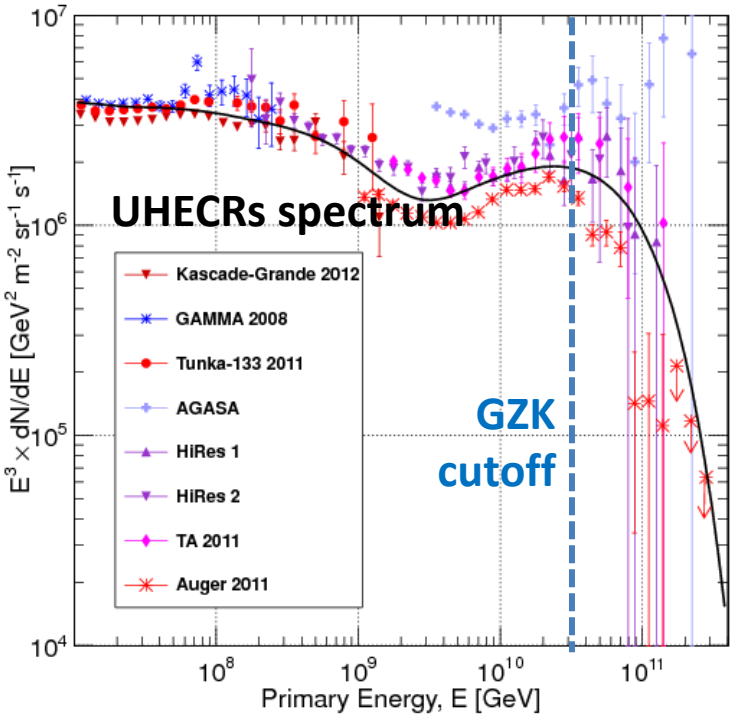
The Giant Radio Array for Neutrino Detection

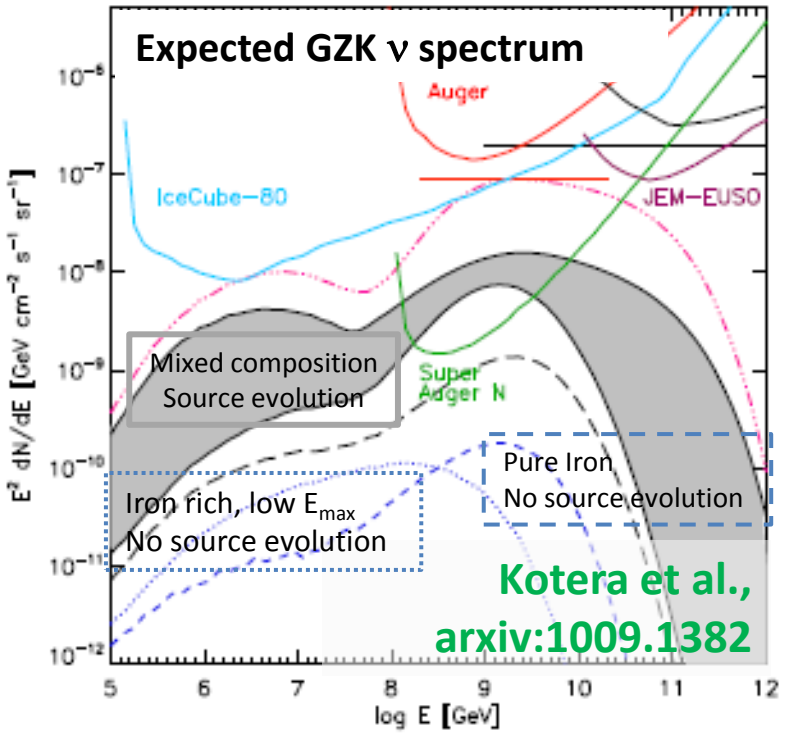
- *Why VHE neutrino astronomy?*
- *The GRAND project: towards a giant neutrino telescope*
- *GRAND-proto*
- *GRAND workshop feedback*

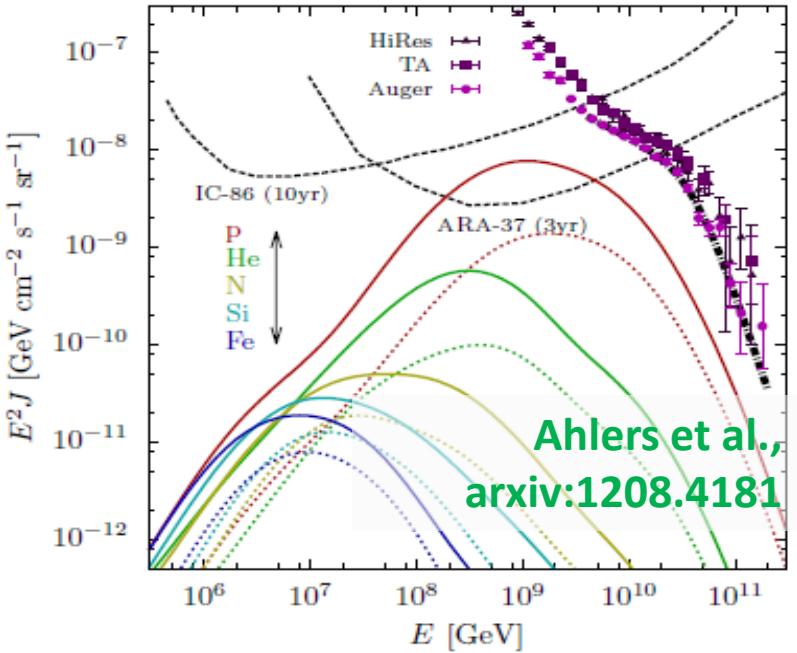
Olivier Martineau

FCPPL workshop, April 9, 2014

Physics with UHE cosmic neutrinos







- GZK neutrinos for UHECRs above $10^{19.5}$eV:

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

$\pi^+ \longrightarrow l + \nu_l$

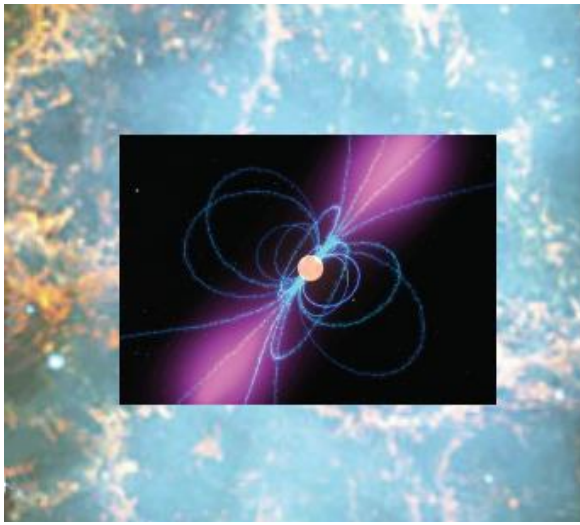
«Garanteed» flux

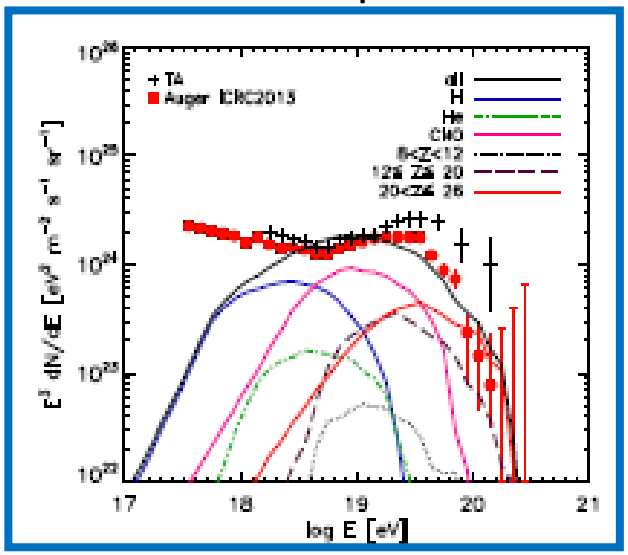
Great tool to study UHECRs.

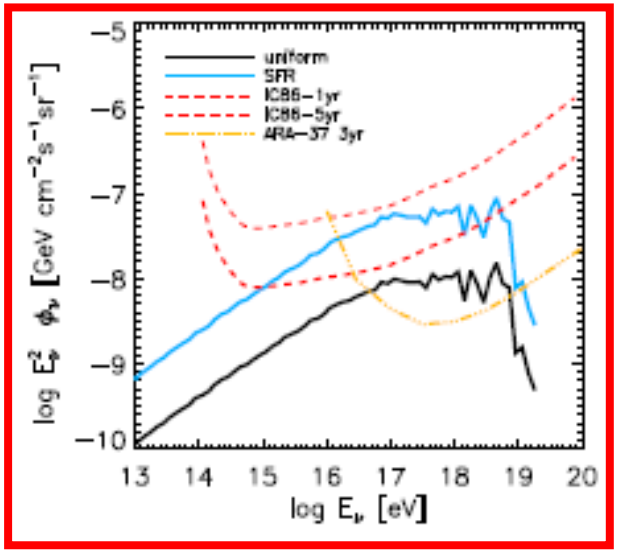
Physics with UHE cosmic neutrinos

- UHE neutrinos as a tool to study violent phenomena in the Universe
  - One example: young extragalactic pulsars

    (Ke Fang et al., arXiv:1311.2044)
    - UHE heavy nuclei emmited (= **UHECRs**)
    - Interaction with supernova ejecta
    - $\pi^+ \longrightarrow l + \nu_l$ (= **UHE neutrinos**)

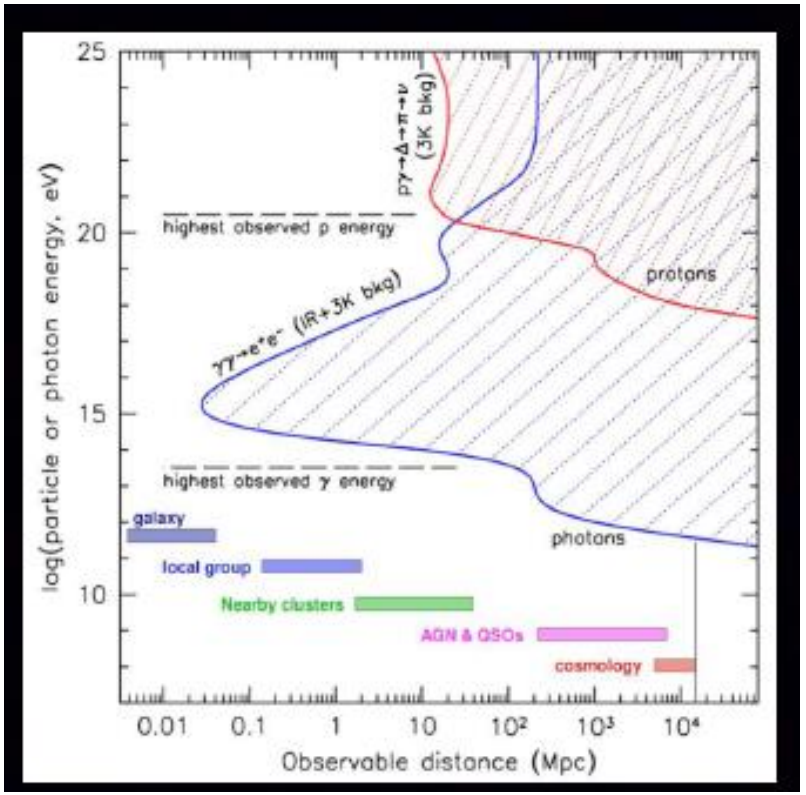






Physics with UHE cosmic neutrinos

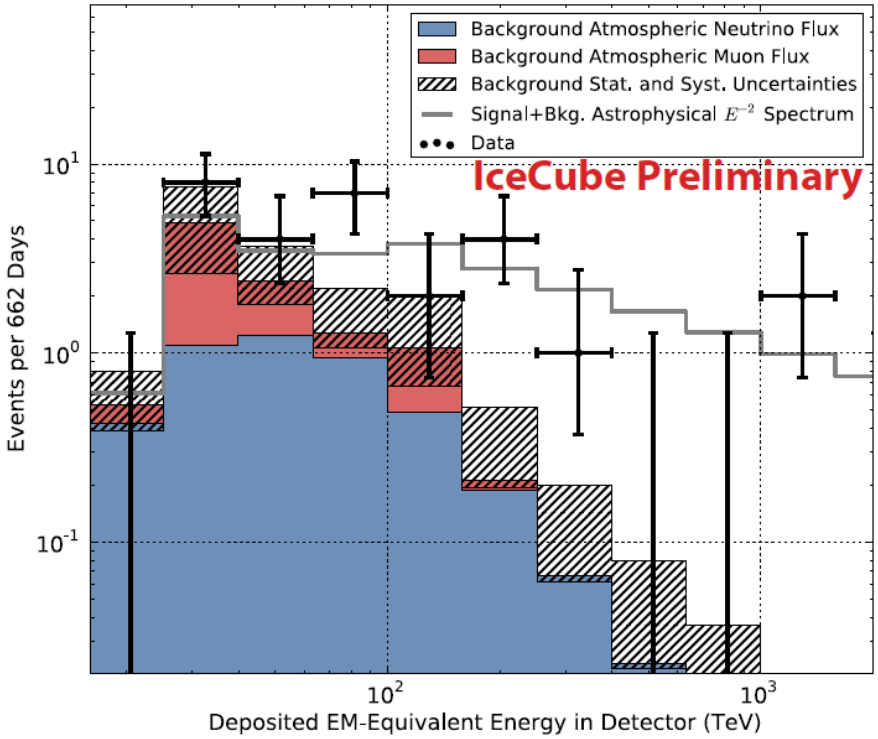
- Lots of physics with neutrinos above 10^{16}eV
  - Test of pulsars, AGN, GRBs,
  - Test of UHECRs propagation
  - Probe distant Universe
  - …
- Downside: neutrino detection challenge + low flux @ UHE…

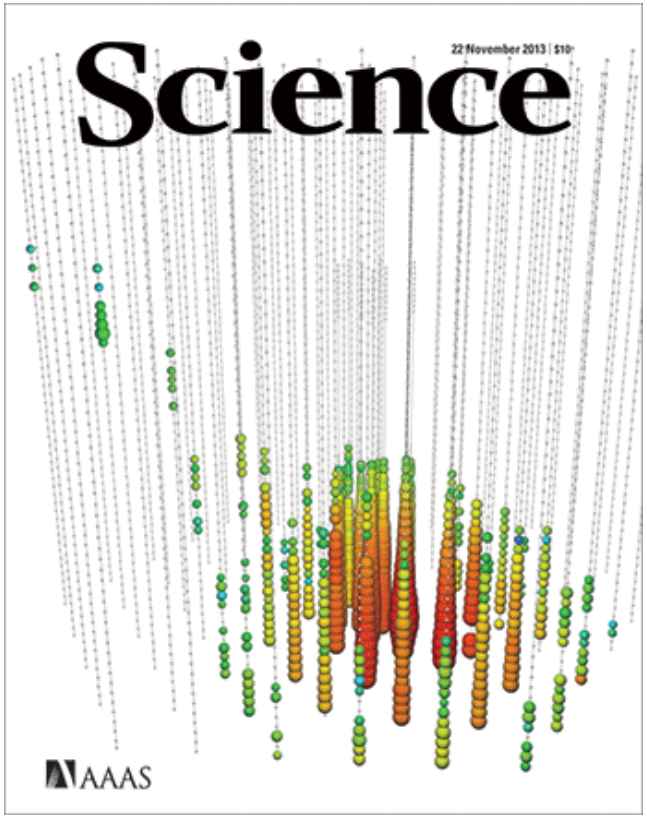


Need for cheap / scalable /easily maintainable detector.

Birth of neutrino astronomy

- IceCube 2012&2013
  - Milestone in astronomy & astrophysics but:
  - Poor angular reconstruction for shower events
  - ~1 event/year above 250TeV => **DecaCube**

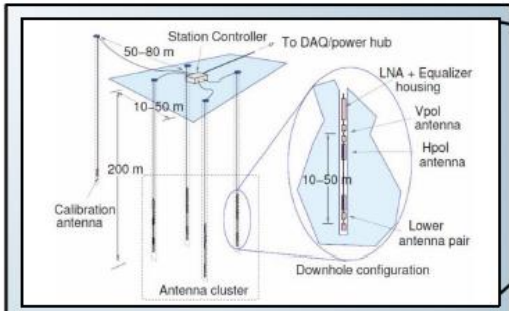




Radio in Antartica

- Askaryan Radio Array (ARA)

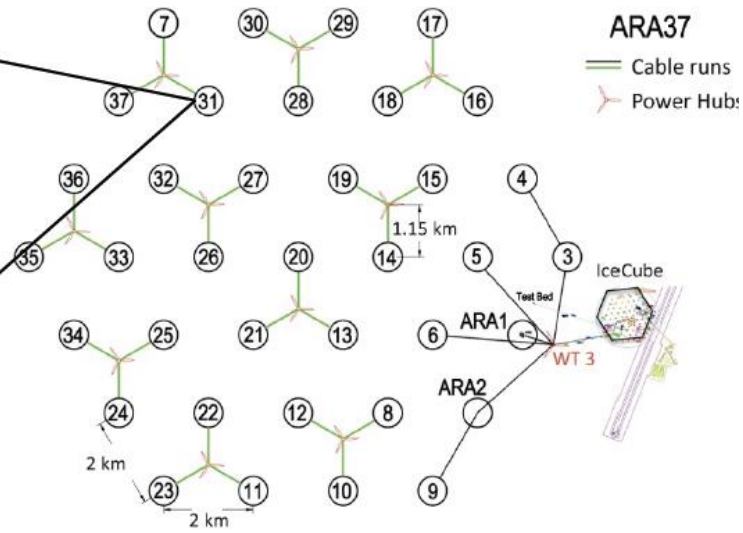
ARA 37 Layout



Single Station
Measurement systems:
- 16 antennae, 150-800MHz (8 h. pol, 8 v. pol)
- 4 holes ~20m spacing
- DAQ electronics, computer

Calibration systems:
- 2 holes ~40m distance
- 4 calibration antennae (2 h. pol, 2 v. pol)

Each station can act as a stand alone neutrino detector



37 Stations
200m below the surface
~200km² coverage

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

ARIANNA

http://arianna.ps.uci.edu

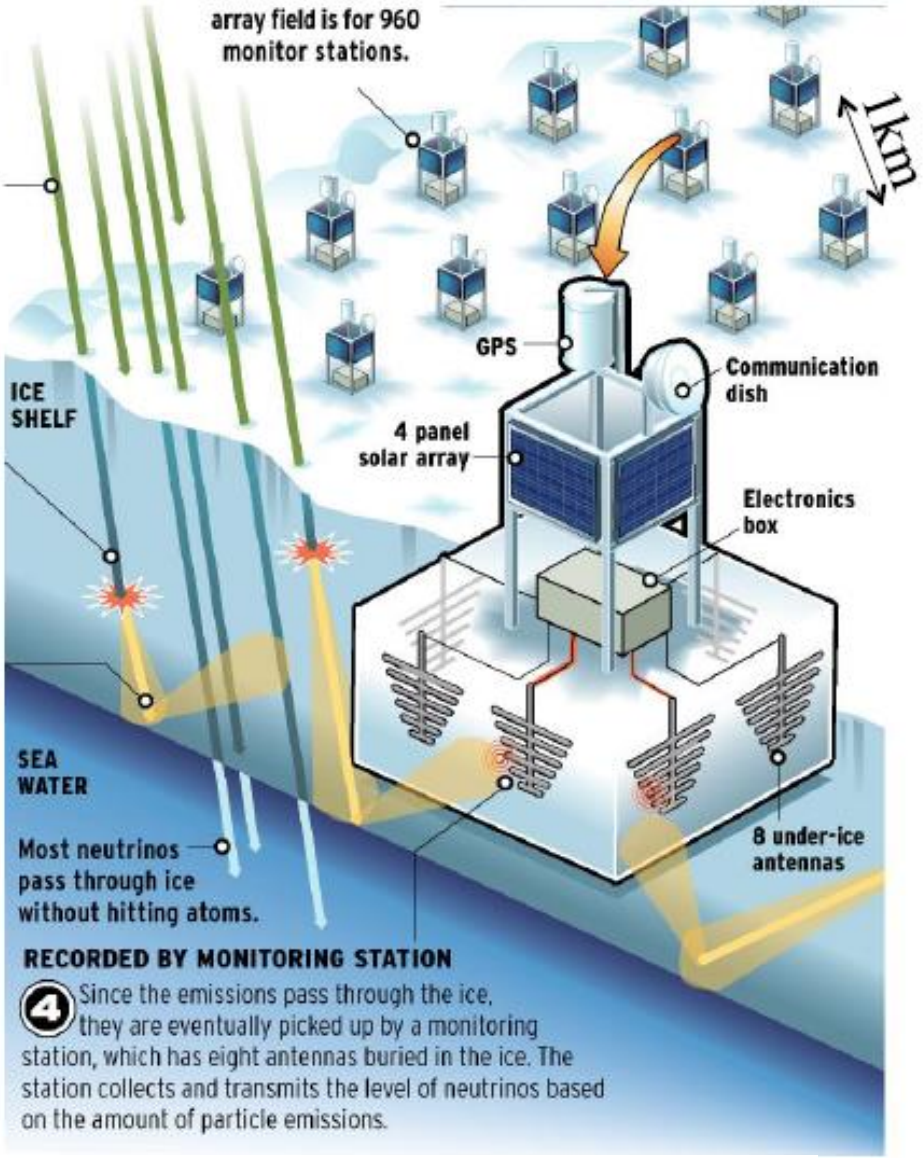
Steve Barwick, UCI

for the ARIANNA collaboration

US

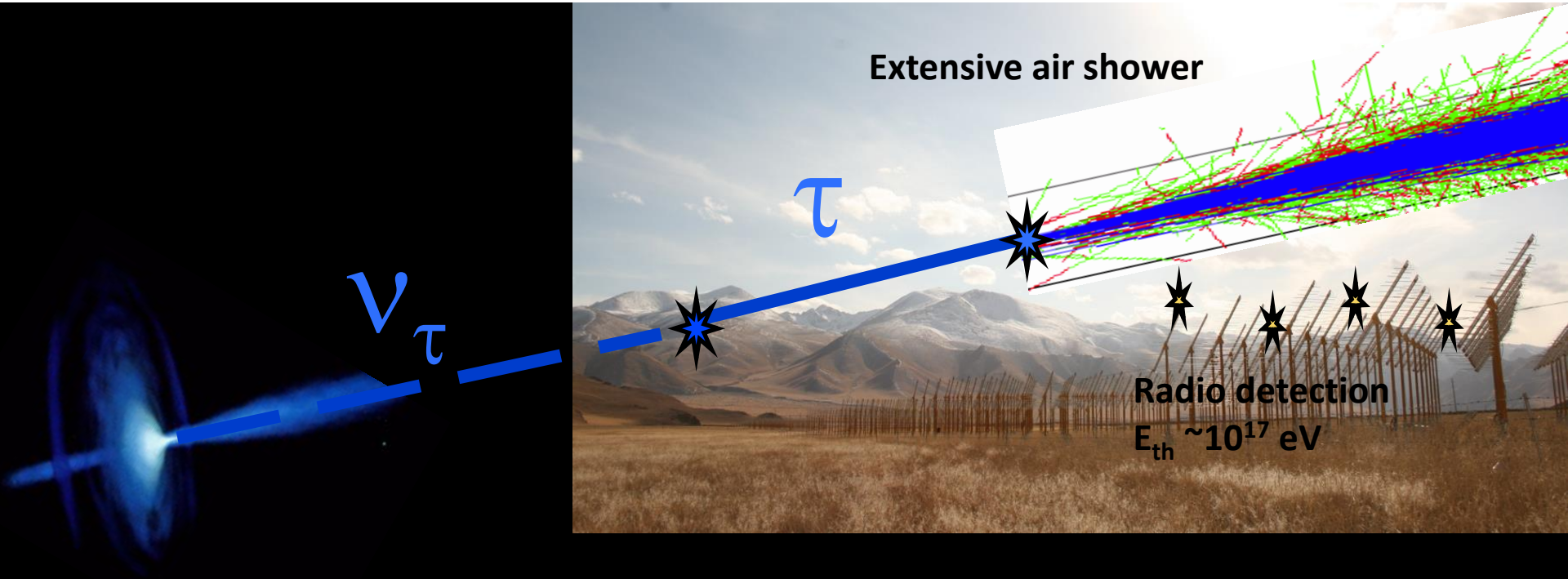
Sweden

New Zealand



Cerenkov radiation far beyond visible spectrum, up to radio frequencies.

Neutrino detection

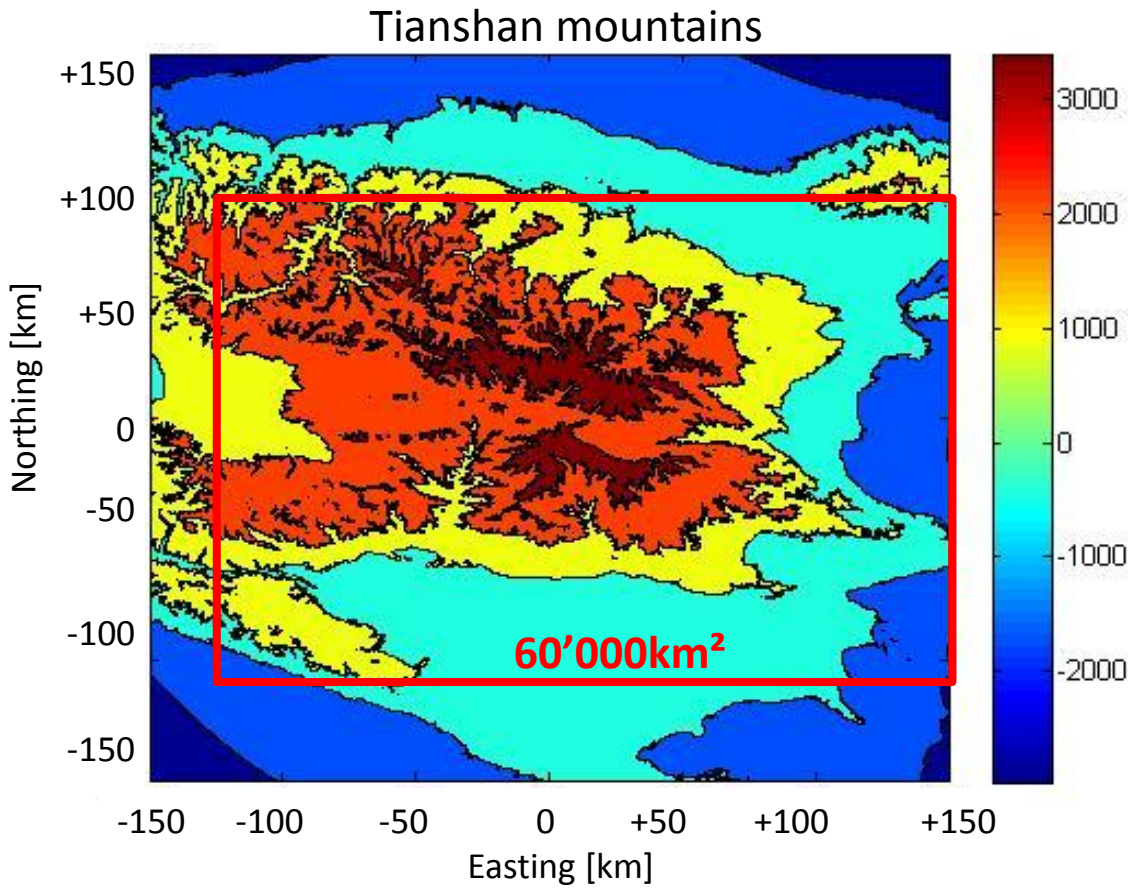


- Earth + mountains as target for neutrino interaction
  Fargion et al, astro-ph/0002.453, Bertou et al., astro-ph/0104.452
- Radio detection of subsequent EAS (good at large zenith angles)

A radio telescope dedicated to neutrino detection

Baseline setup: 90'000 antennas deployed over 220x270km² in Tianshan

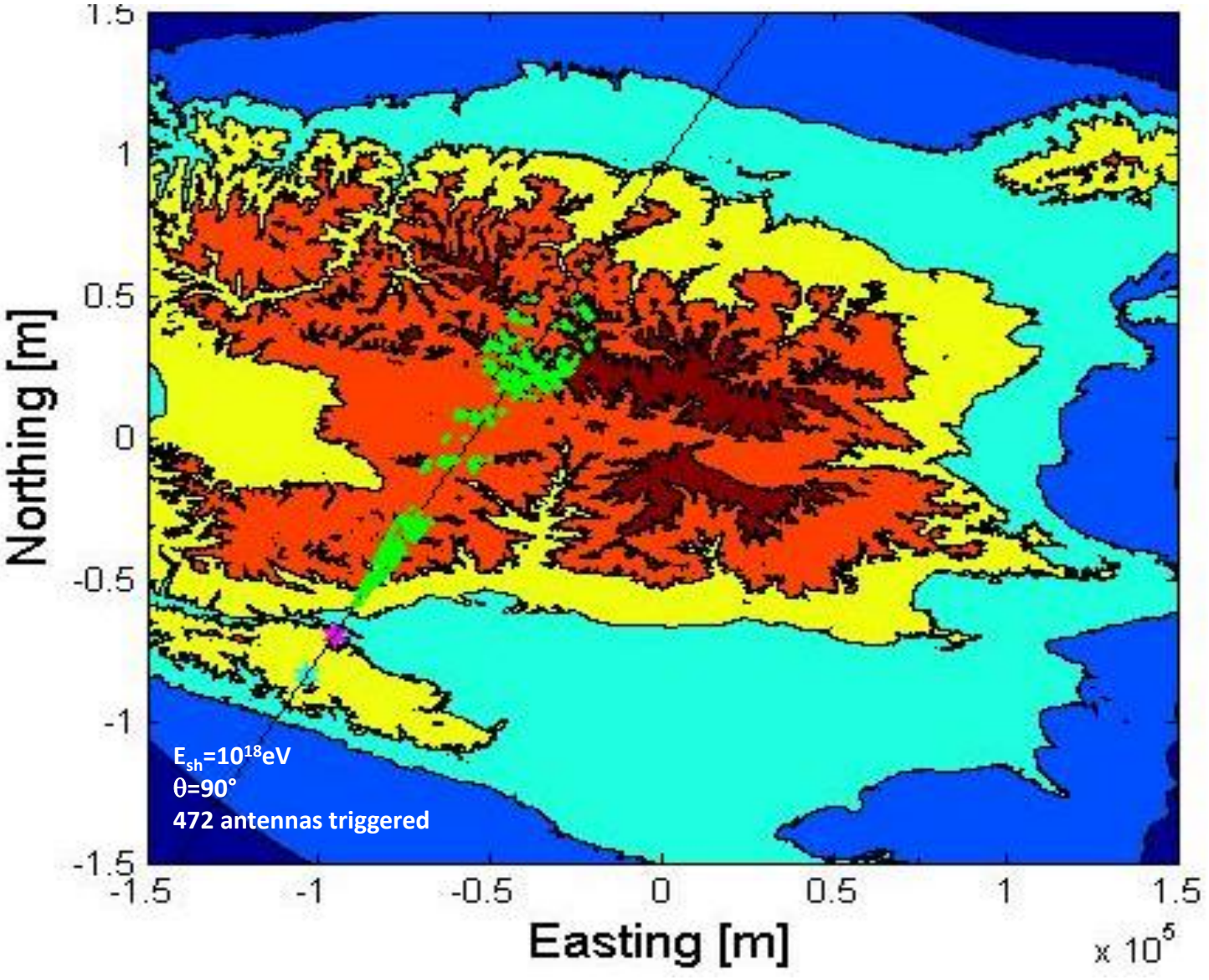
Giant Radio Array for Neutrino Detection (GRAND)



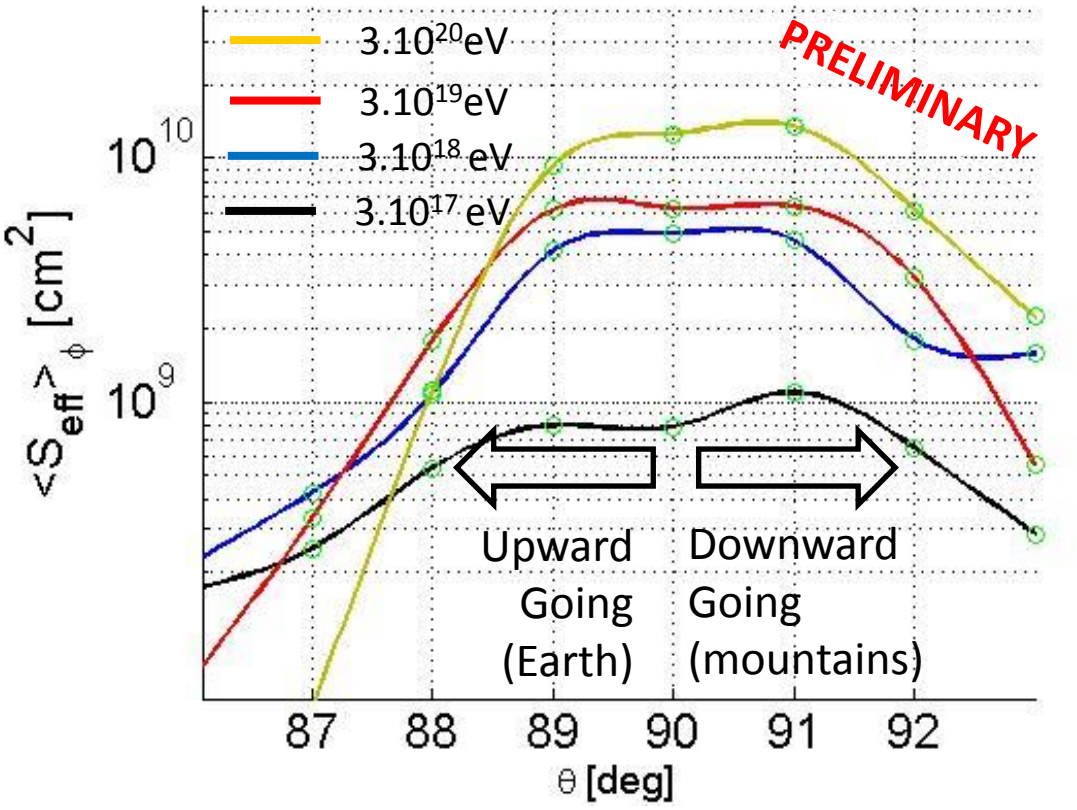
Neutrino sensitivity study

End-to-end MC

- Neutrino traje
- Neutrino inter
- Tau energy los
- Tau decay (PY
- Shower develo
- Radio signal g
- Antenna respo
- Trigger (TREN

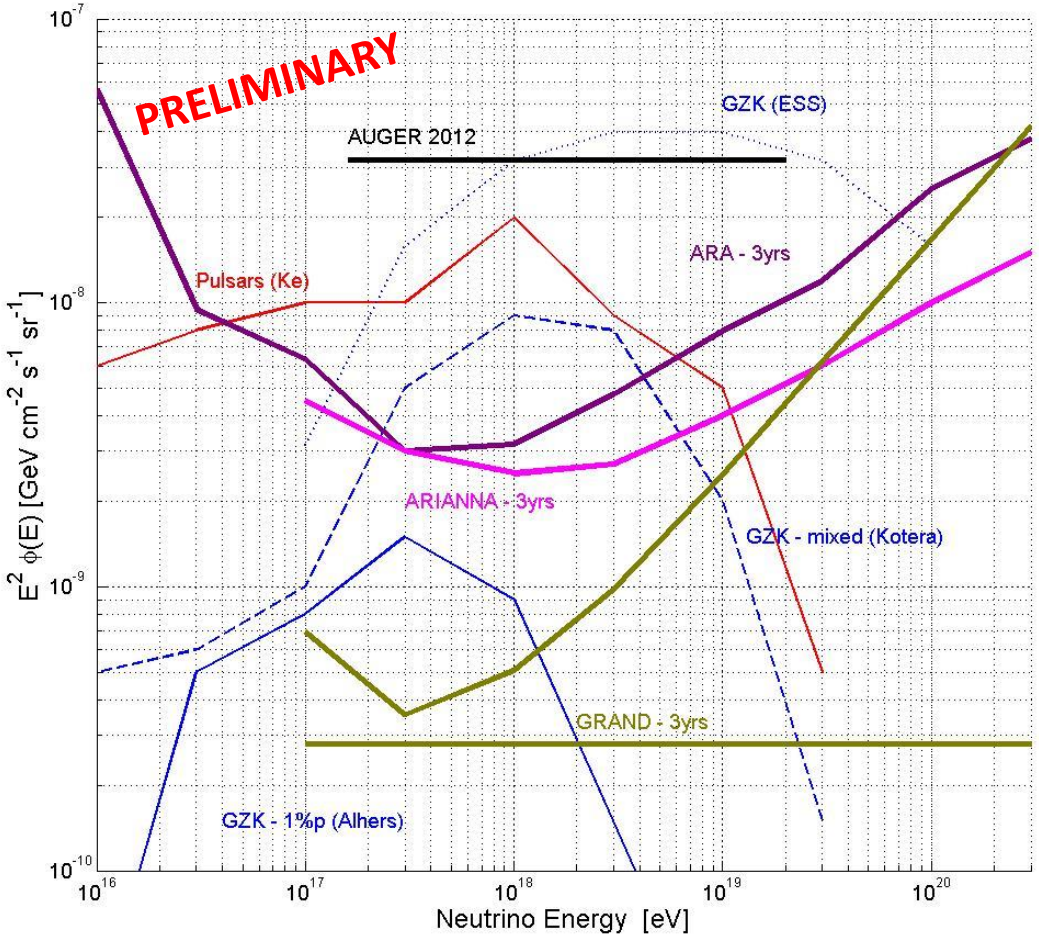


Simulation results



- ~ Horizontal trajectories.
- Mountains are sizable tragets.
- Many extended tracks (<mult> = 190 antennas).
- Angular resolution: $\langle \Delta\theta \rangle < 0.1°$ (assuming $\Delta t \sim 1ns$)

GRAND neutrino sensitivity



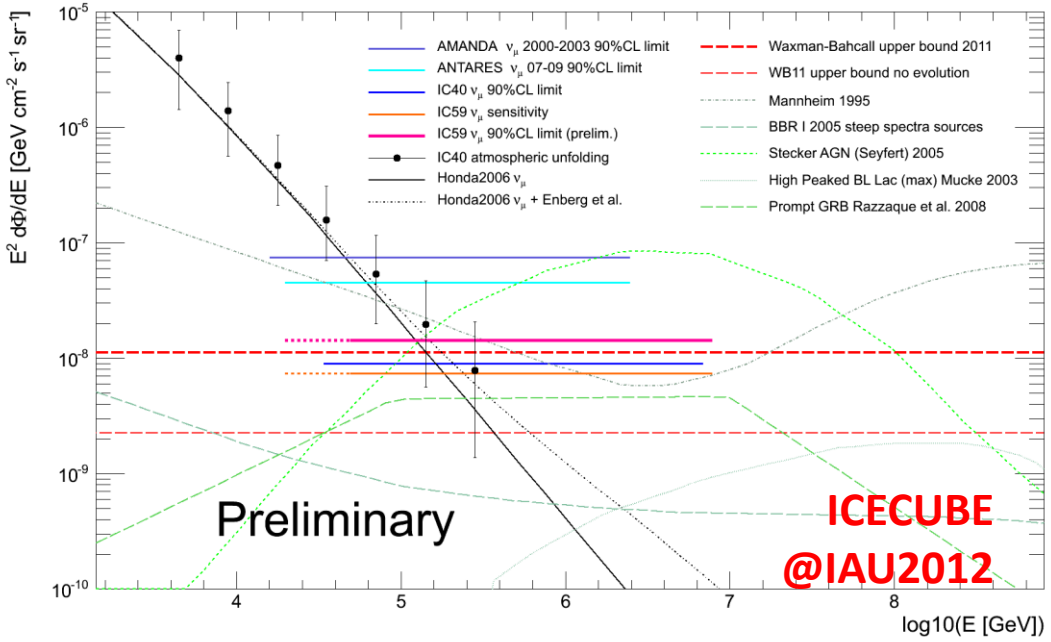
GRAND :
90% CL limit assuming

- 0 candidates in 3 years
- threshold = 3 10^{16}eV
- $\Phi = \Phi_0 E^{-2}$ spectrum

Tens of GZK ν /year expected!

GRAND could reach 5-10x better sensitivity than Antartica projects.
Angular resolution better than 0.1°.
To be confirmed/optimized with full MC.

Background rejection

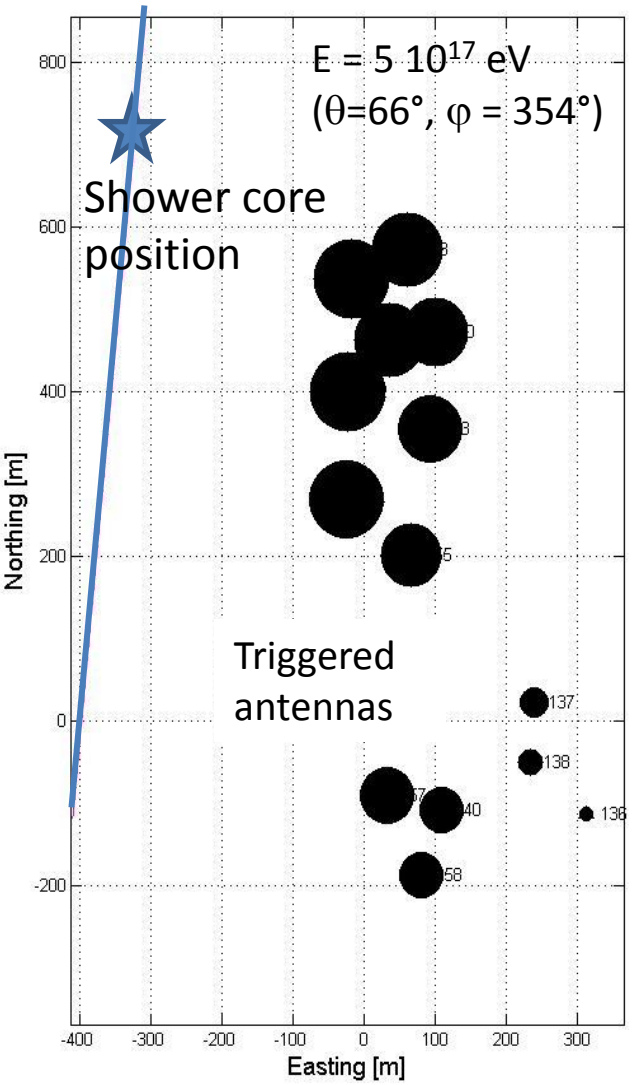


- Atmospheric neutrinos: negligeable at high energy √
- HE muons: ~3 10^{-6} decays/year over full array above 10^{16}eV √
- Standard cosmic ray EAS: cut trajectories down to 1° below horizon

  => **5 10^{-7} flux suppression factor** √
- **Non-cosmic background: expected trig rate ~10^9 x ν event rate! ?**

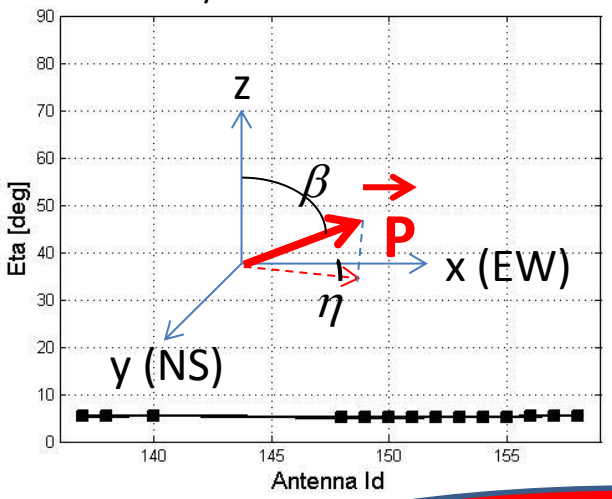
EAS polarization info

Simulated radio event

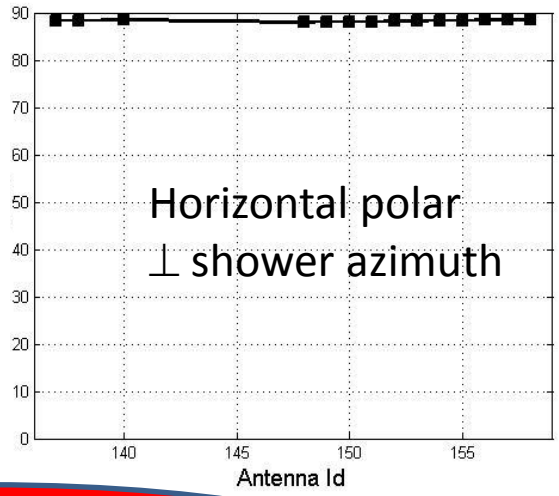


- TREND selection algorithm not valid on event by event basis, and affects detection efficiency.
- More efficient method needed for GRAND!
- EAS radio E-field linearly polarized:
  - $\perp \mathbf{B}_{geo}$
  - $\perp$ direction of propagation

η=atan(E_y/E_x) ~7° on all antennas



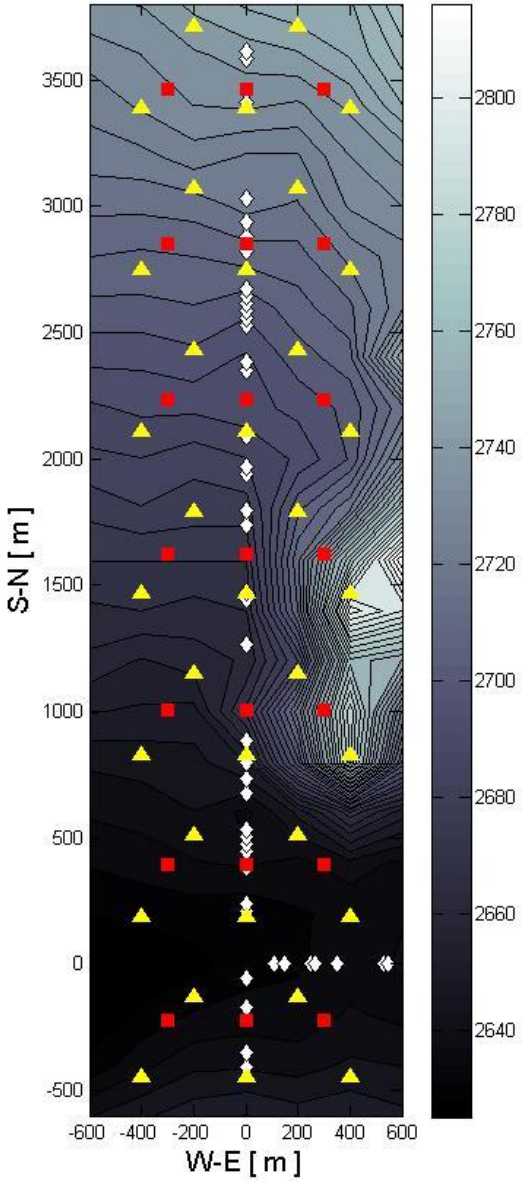
β=atan(E_z/E_{plan})~89° on all antennas



Efield polarization provides a very specific signature!
Could allow tagging of EAS events (?)!

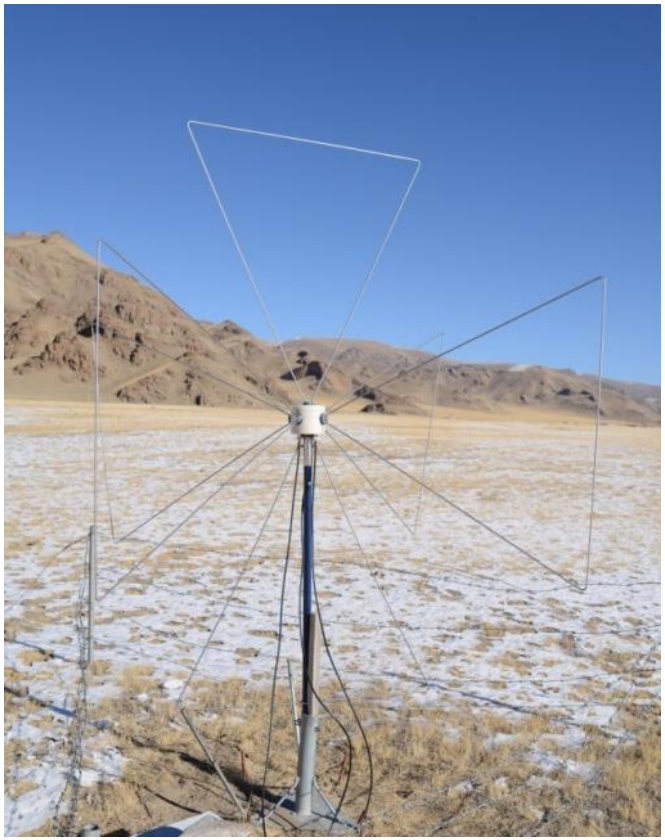
GRAND-proto

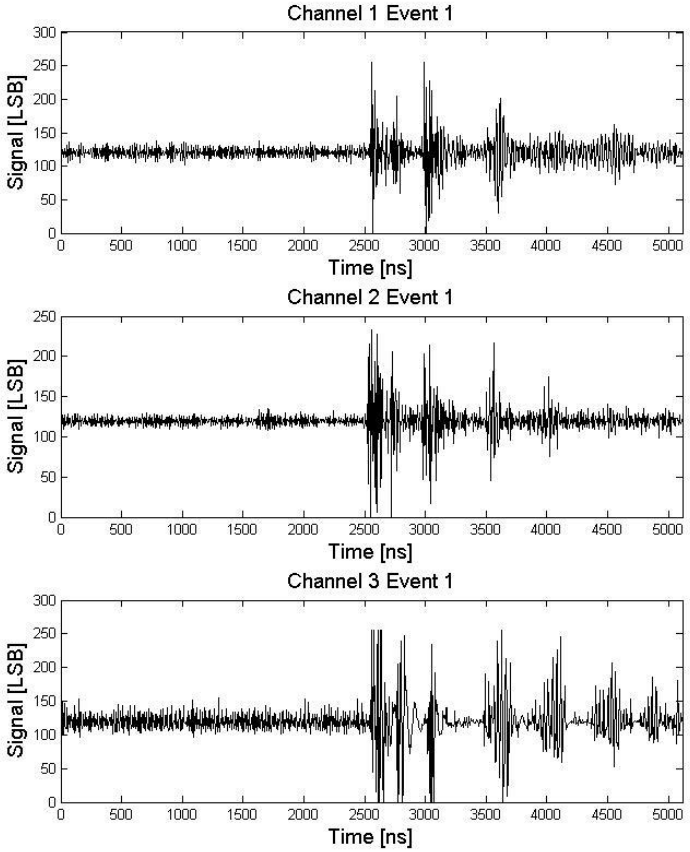
- Test setup: «GRAND-proto»: a hybrid setup to evaluate quantitativly bckgrd rejection potential of polarization information.
- Principle:
  - 35 **3-polar antennas** for a complete polar measurement:
    $\eta^*=\text{atan}(V_y/V_x)$ & $\beta^*=\text{atan}(V_z/V_{plan})$
  - Reconstruction of events & selection of candidates with polarization pattern consistant with EAS.
  - Off-line validation of candidates with **scintillator array** (21 units)



GRAND-proto status

- Fully funded, deployment starts next May.
- Radio antenna status
  - 3D active antennas (CODALEMA/AERA type, D. Charier @ SUBATECH + Xi'An XiDian DaXue)
  - 6 prototype antennas in test in January-May 2014.

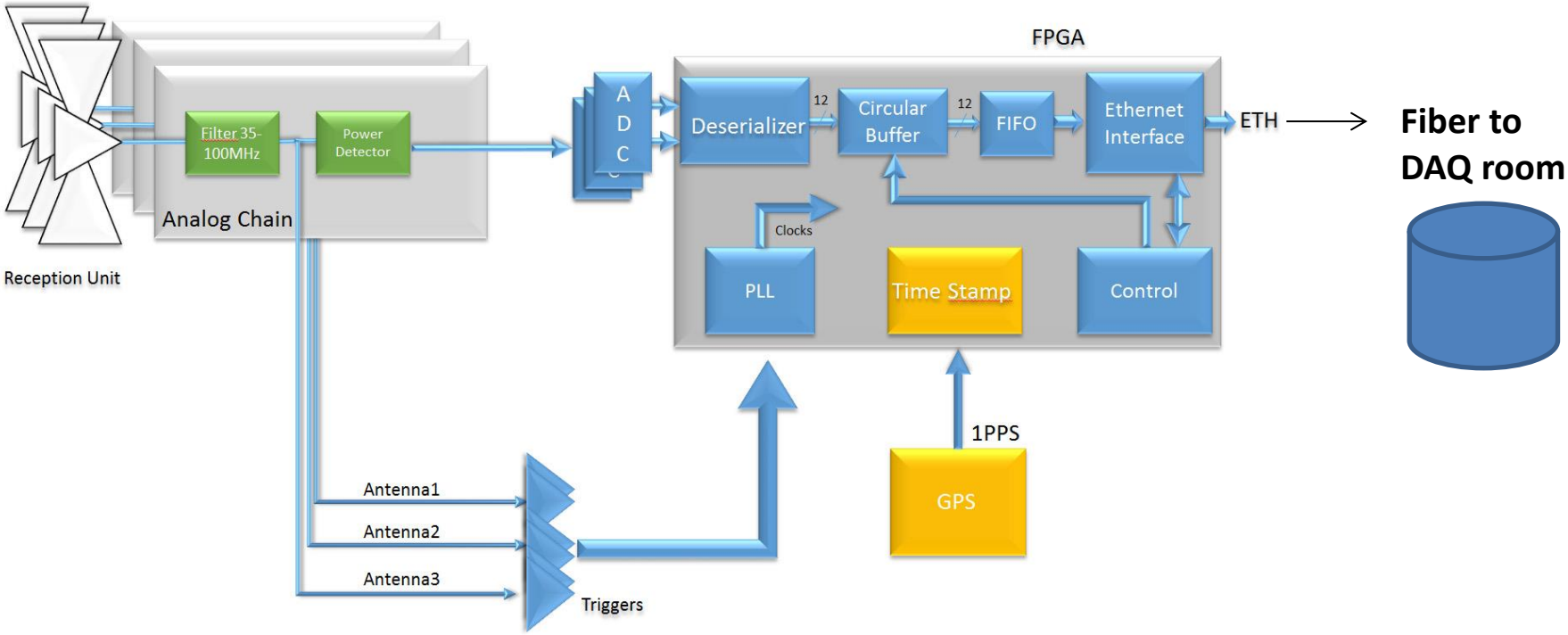




1 event triggering all 3 channels

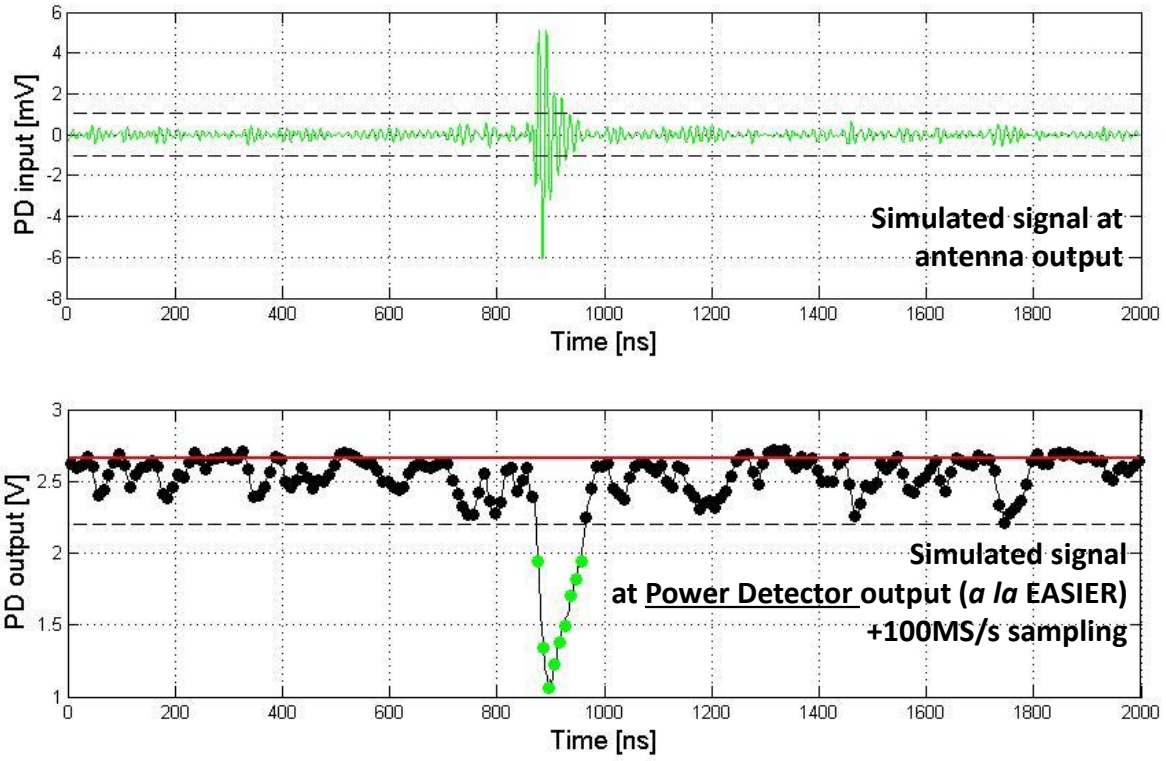
GRAND proto status

- Radio array DAQ
  - Early digitization, trig rate up to 10kHz, ns timing precision.
  - Being developped @ LPNHE Paris
  - On-site test in autumn 2015, 35 units to be delivered beginning 2016.



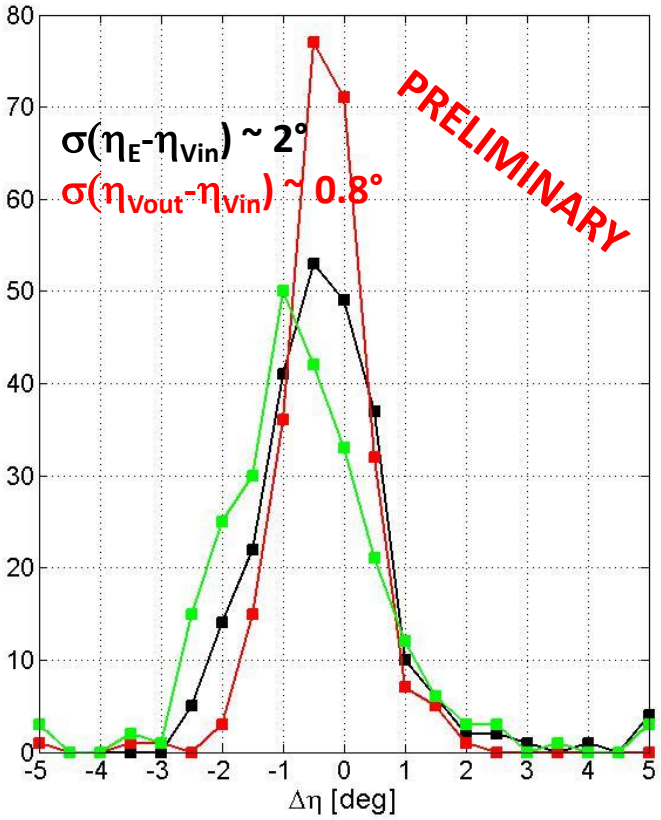
GRAND-proto DAQ

- Simulated performances



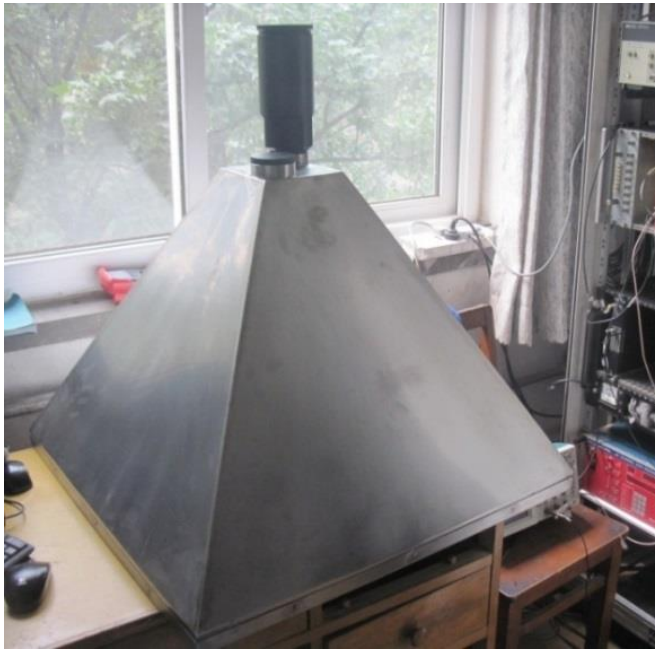
Power detector measures signal enveloppe.
Allows slow sampling (100MS/s).

System will perform reliable measurement of wave polarization: $\sigma(\eta_{Vout}-\eta E) < 2°$

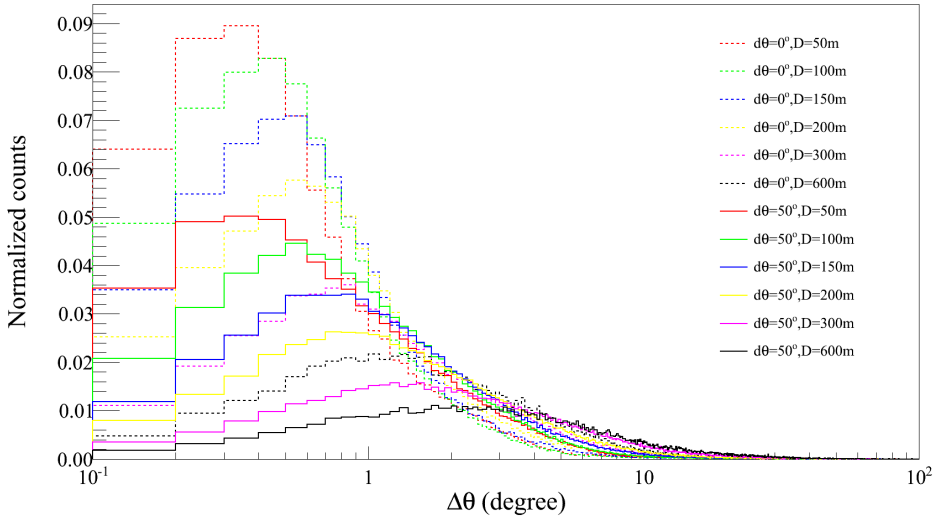


GRAND proto

- Scintillator array
  - Funded through NSFC (IHEP: Gou QuanBu, Hu HongBo, Zhang Yi, Feng Zhaoyang, Guo YiQing)
  - Hardware being tested @ IHEP
  - Simulation ongoing to determine optimal layout & detection efficiency.
  - 9 units to be deployed summer 2015

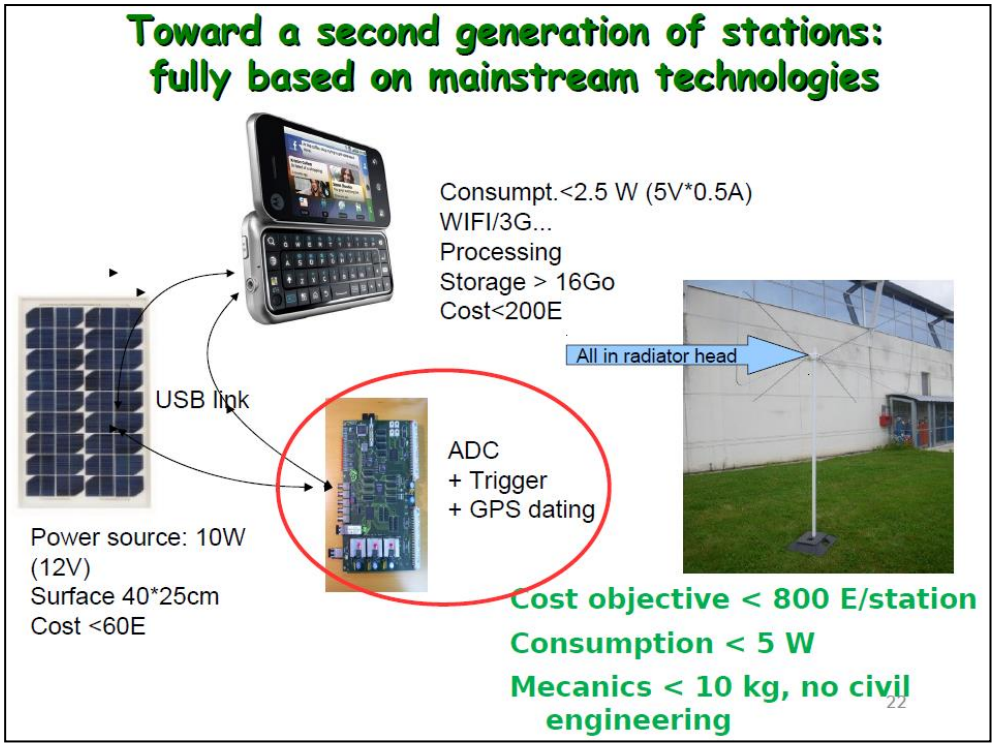


Simulation output



A 90kAntennas array ?

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



P. Lautridou Clermont GHz workshop, 2011

Recent developments

GRAND exploratory workshop (LPNHE, Feb 9-11, 2015)

- 37 participants from various countries & expertise.
- New collaborators (Brussels, Santiago di Compostella, NIKHEF, Karlsruhe (?)…)

- Conclusion: be EVEN MORE ambitious!
  - Target: 100 cosmogenic neutrinos/year -> **200'000km² needed**.
  - Widen science case:
    - include UHECRs (post-AUGER)
    - Astronomy: EoR, FRBs...
  - Groups at work:
    - Science case
    - Neutrino sensitivity simulation
    - Prototypes (with AUGER-AERA)

https://indico.in2p3.fr/event/10976/

谢谢！

Merci！