Autonomous detection of air showers with the TREND radio-array

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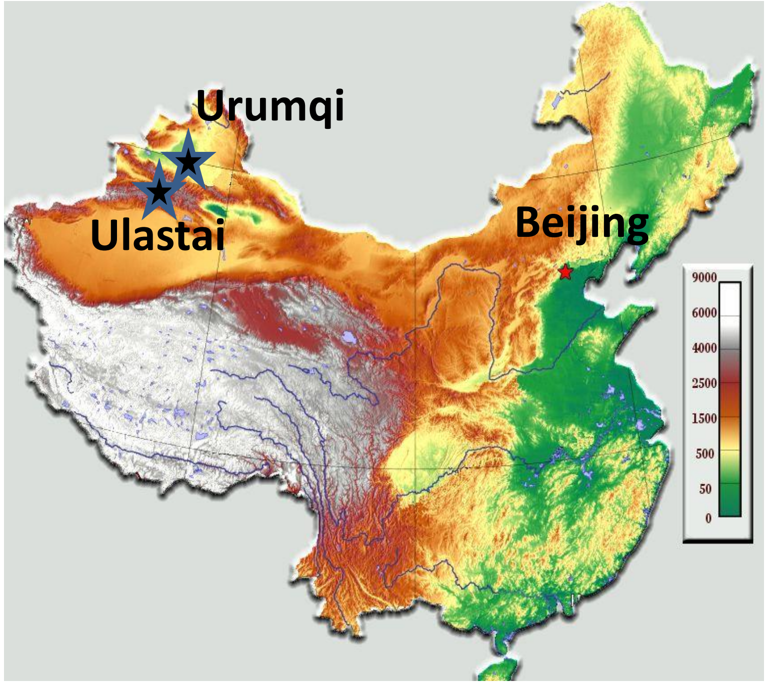
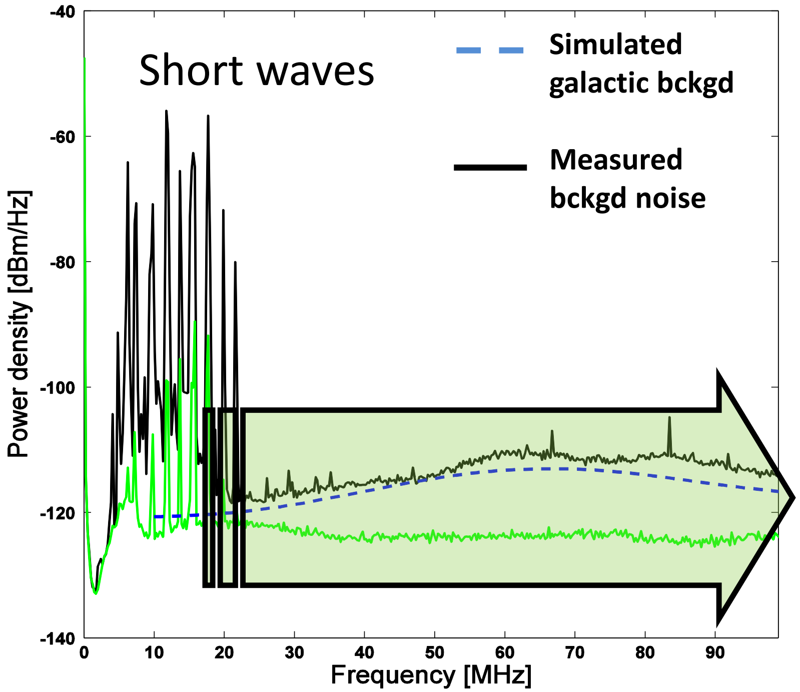
Autonomous radio-detection

- ☺ Cheap, light & robust: radio is an **appealing technique for giant detectors of HE air showers**.
- ☹ **Background sources** are a major challenge for ground-based radio experiments.
- **TREND proposal** (2008): tiny group from China (Wu XiangPing NAOC, Hu HongBo IHEP) & France (P. Lautridou Nantes, V. Niess Clermont-Ferrand, OM Paris/NAOC/IHEP) aiming at **demonstrating that self-triggered radio trigger + identification of air shower is possible**.
- Site: 21CMA radio interferometer, XinJiang Province, China





TREND setup

50 1D antenna (1 polarisation) – trigger rate up to ~ 200Hz/antenna – transfert of analogic signal to DAQ room – on-the-fly digitization – trigger if signal>6 or 8σ – record event if 4+ antenna triggers

DAQ periods :

- EW orientation 2011-2012
- NS orientation 2013-2014

One postdoc lost in the field

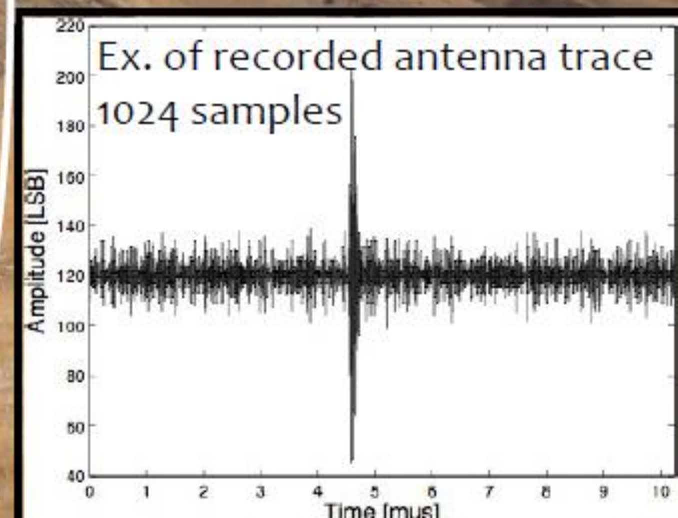
Single polar antenna

Ampli (64 dB) + filter (50-100MHz)

@ pod level (<300m): optical fiber

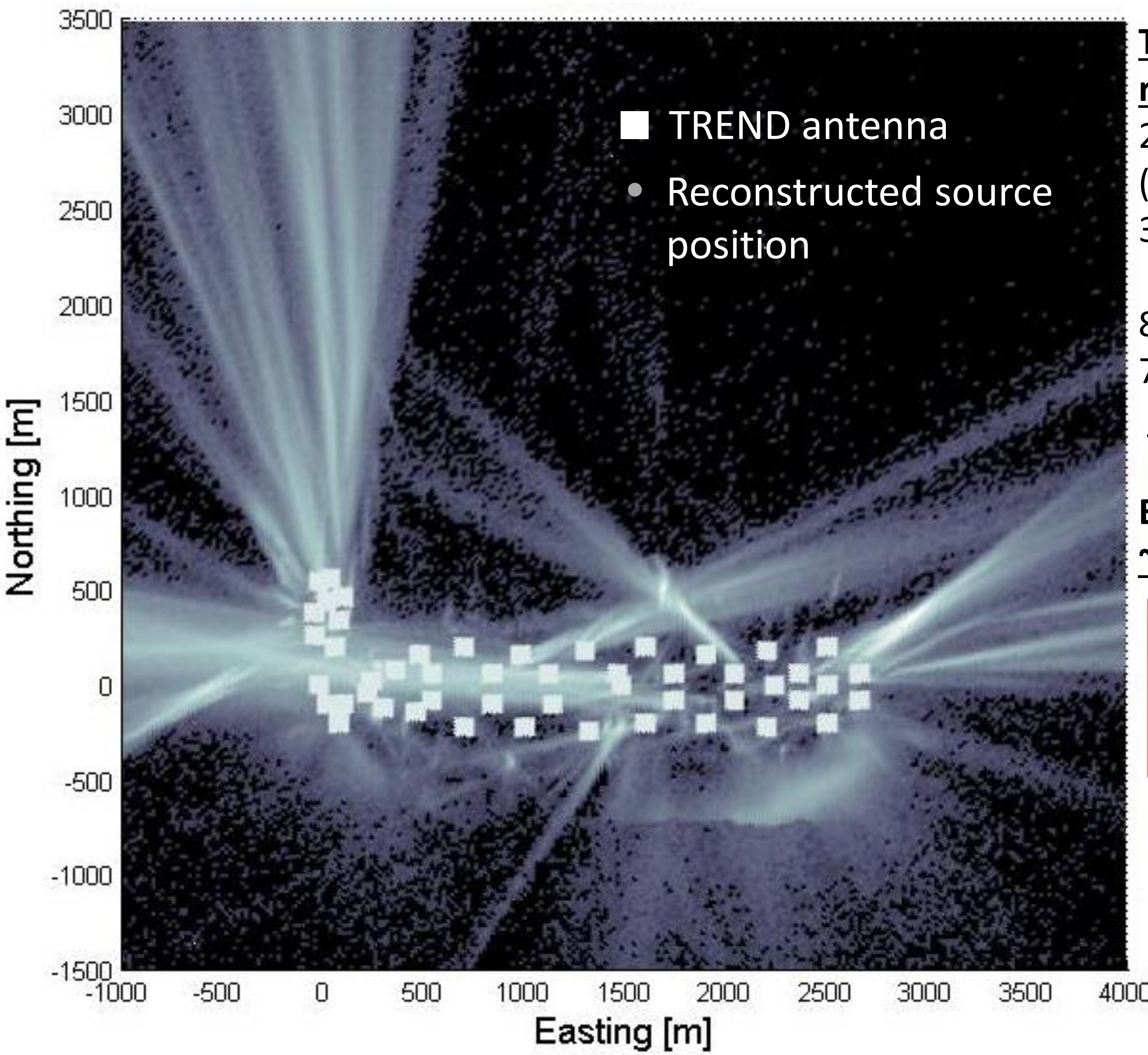
@ DAQ room(<2km): digitization (200MS/s+8bits) +trigger +reccord if 4+ant

Ex. of recorded antenna trace 1024 samples



DAQ= Data AcQuisition

Radio background



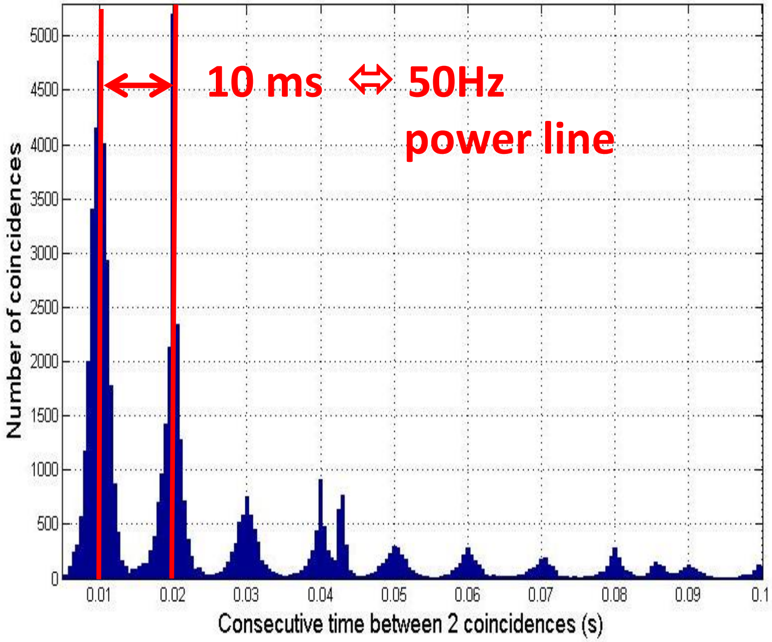
TREND-50 antennas radio array:
2011-2012 data
(E-W polarization)
316 DAQ days analyzed

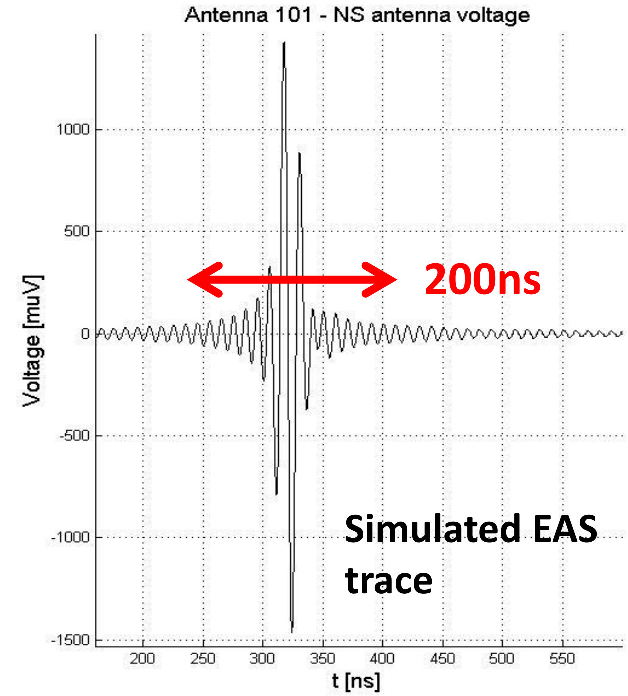
8 10^9 triggers recorded ⇔ **8TBy**
7 10^8 coincidences
~25Hz event rate over whole array (physical origin)
Expected EAS trigger rate: ~40/day

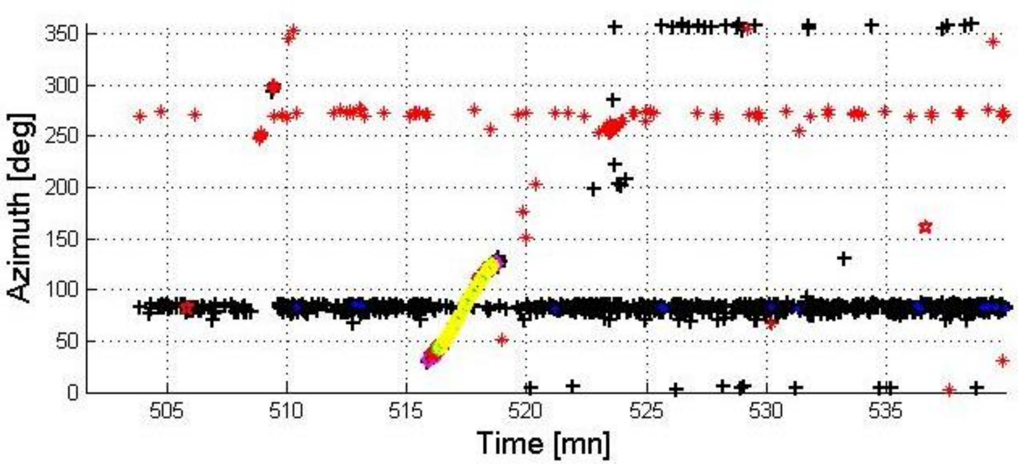
Background rejection is a key issue for EAS radio-detection.

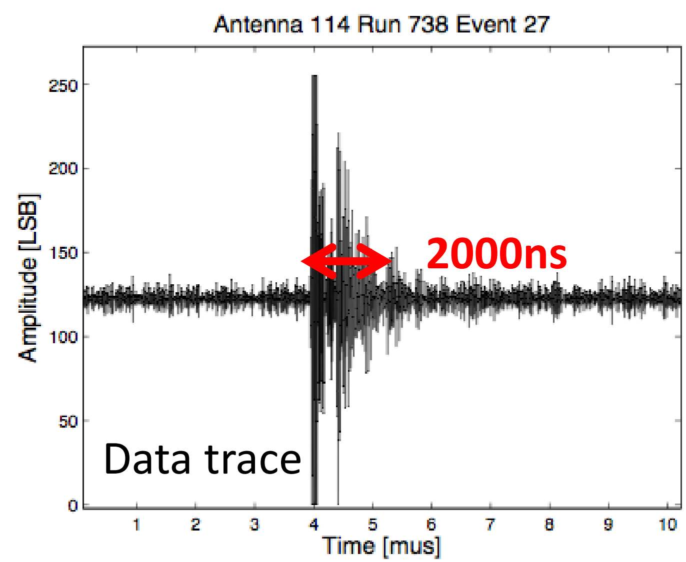
Background sources: HV lines, radio emiters, train, cars, planes, thunderstorms…

Discriminating parameters

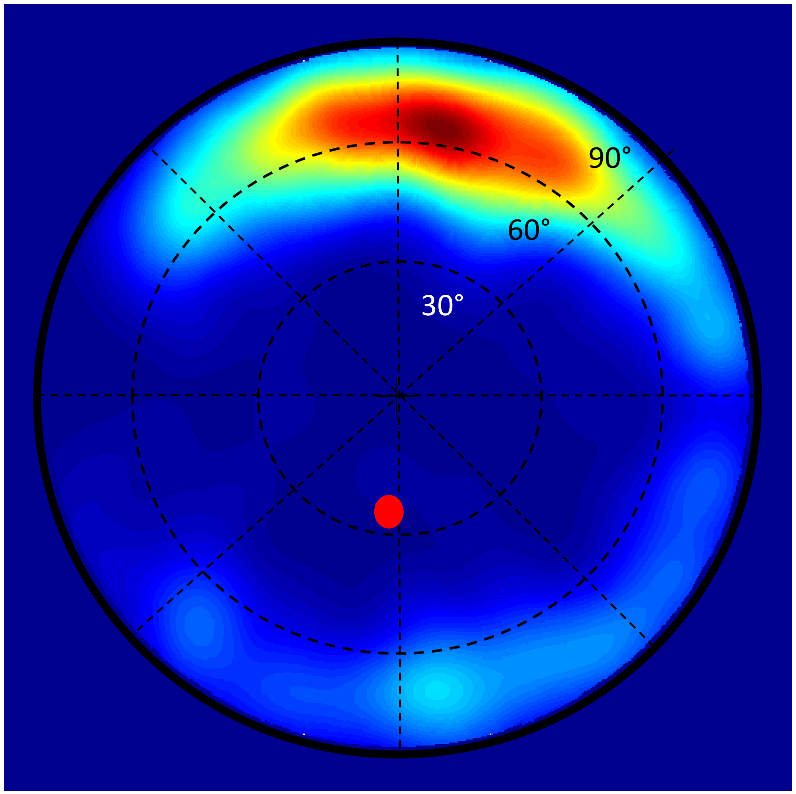




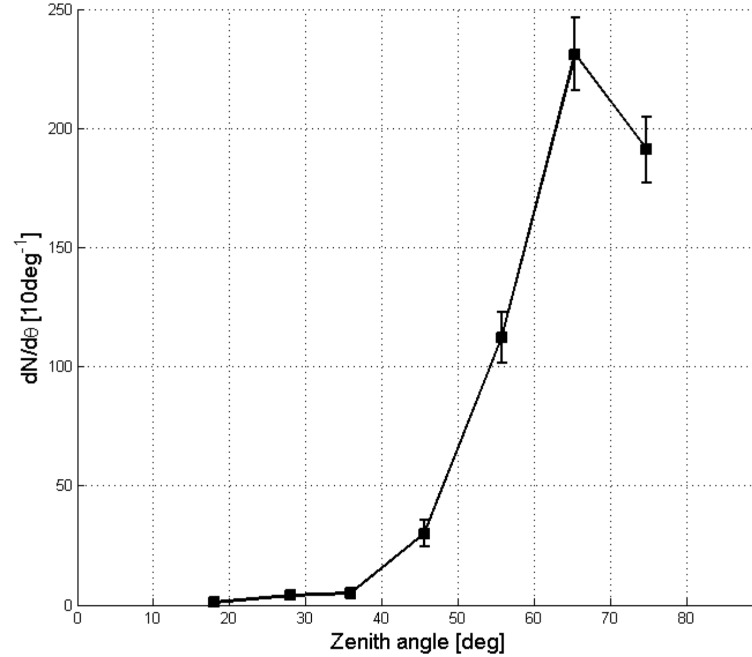


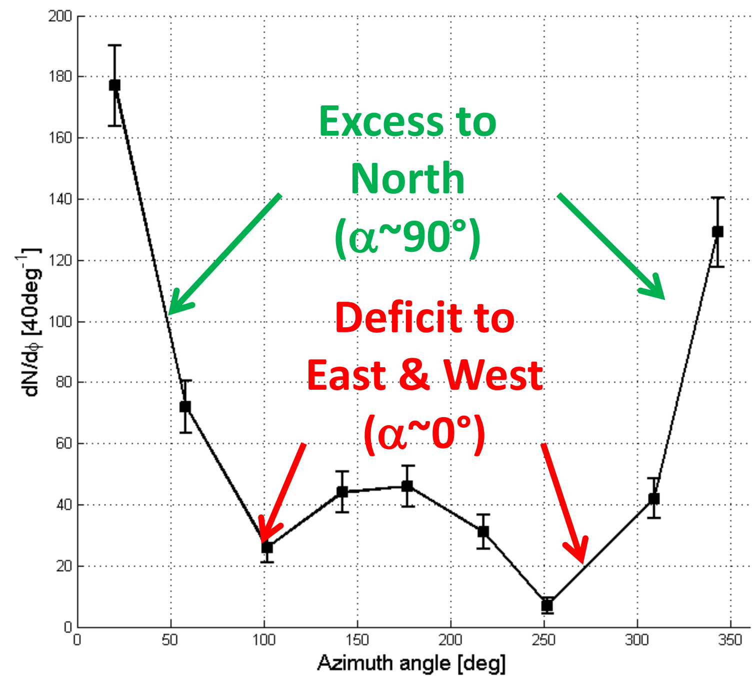


TREND EAS candidates

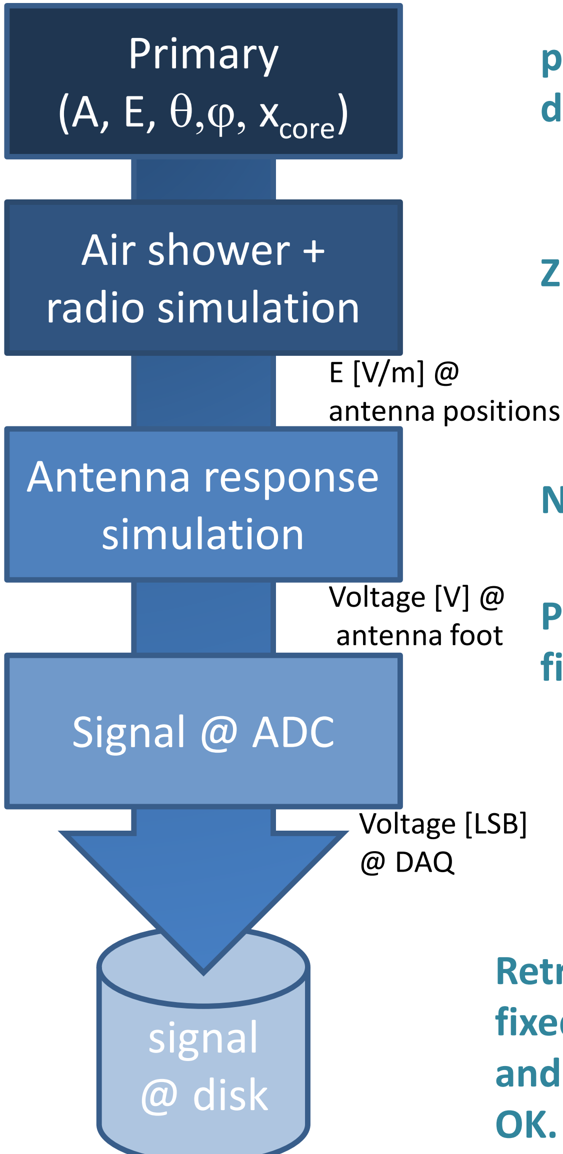


2011-2012 data - 316 DAQ days
EW polar
574 EAS candidates





TREND real-time event simulation



p or Fe, 11 fixed energies in [5 10^{16}, 5 10^{18}eV], random sky distribution & random core position (<1km of detector)

ZHAireS or Conex+EVA. ~8 10^{6} simulation so far (and running)

NEC2 code

Propagation through DAQ chain at fixed random time

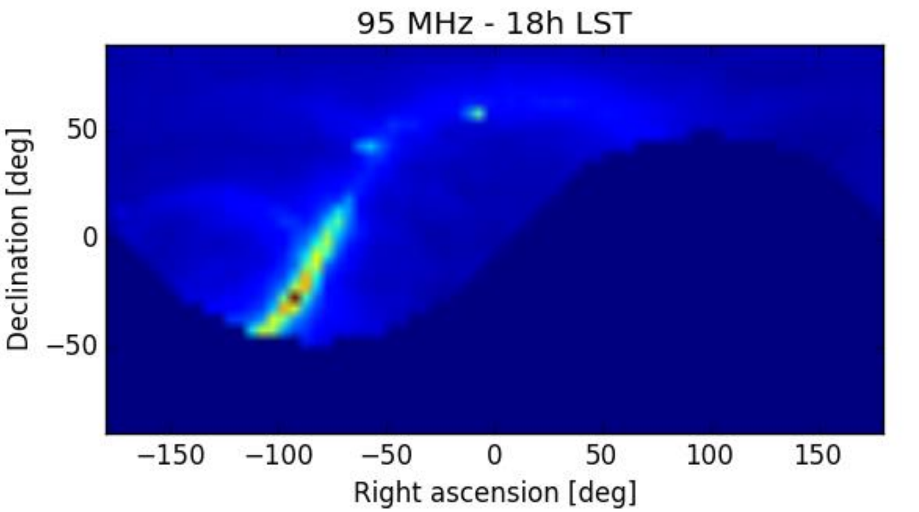
Calibration: g(t)

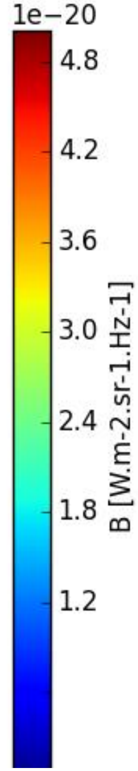
Retrieve noise & computer status at fixed random time. Evaluate trigger and select event if 4+ antennas are OK.

Selected simulated events inserted in data set. Perform blind analysis. Completed on 80 days subset so far.

TREND calibration

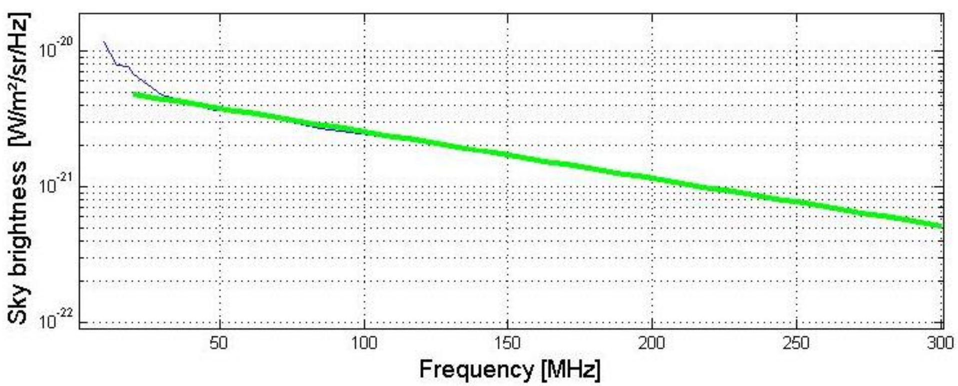
[S. Le Coz, V. Niess]



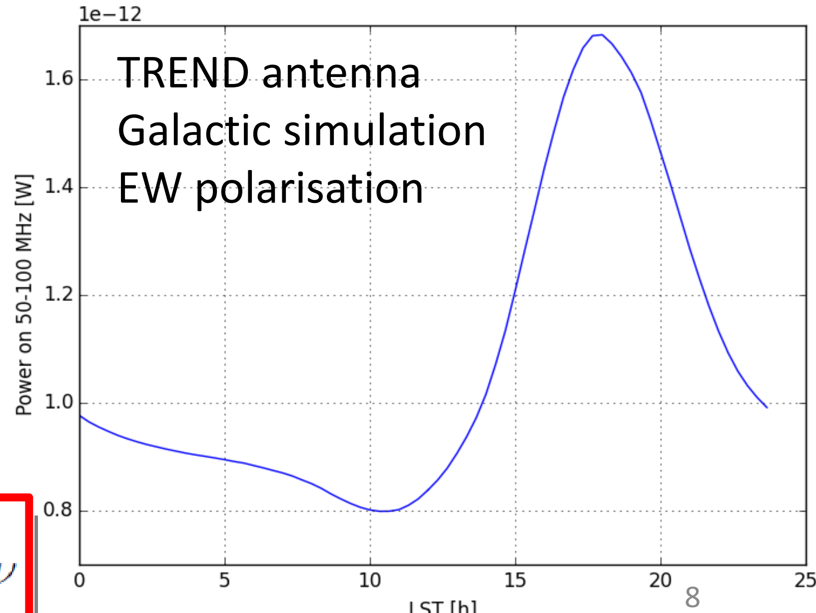


95MHz sky in TREND antenna FoV @ 18h LST

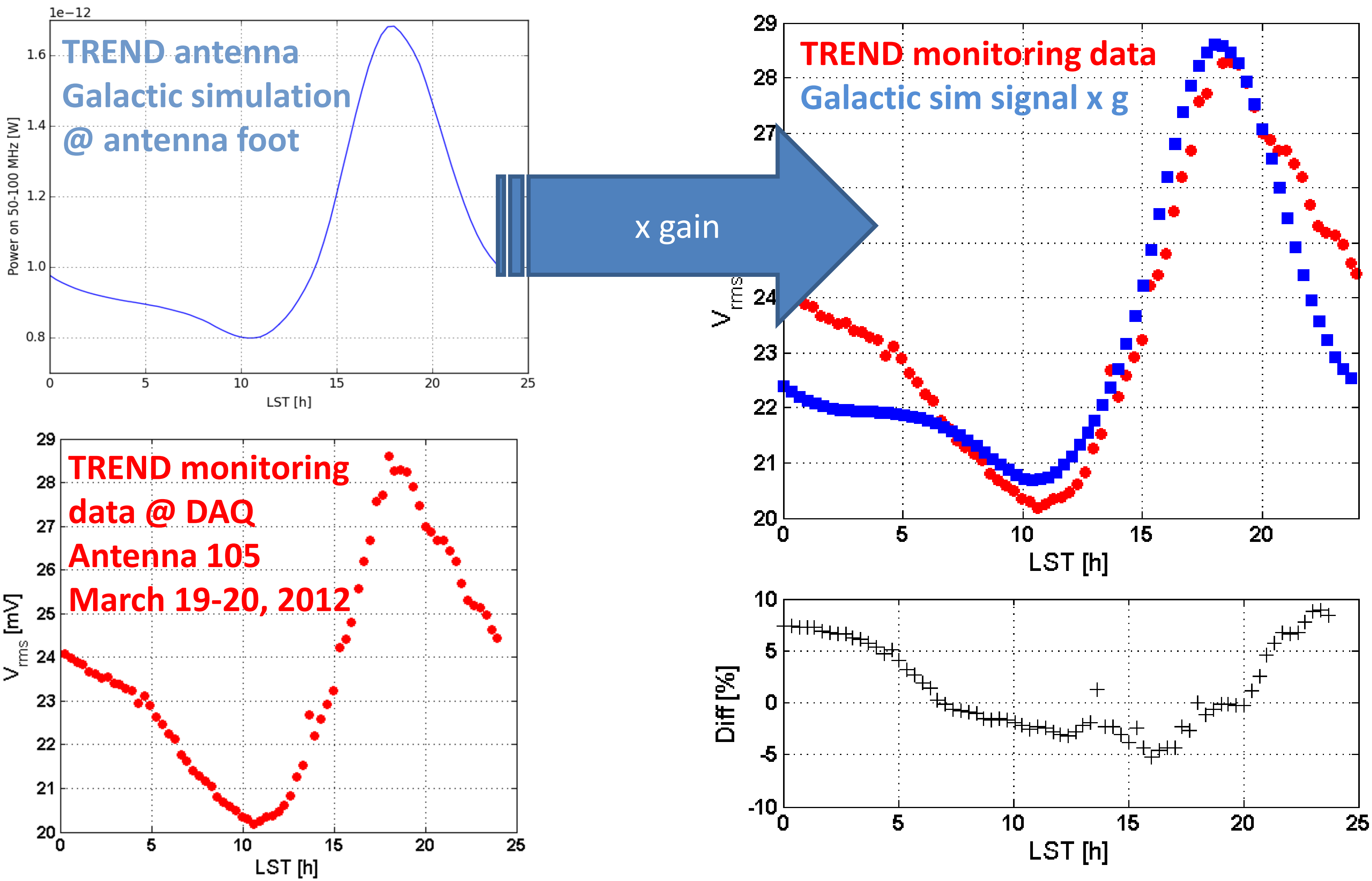
- In TREND frequency range, sky emission highly dominated by Galactic plane radiation.
- Very well known ➔ provides a stable & periodic source for calibration & monitoring.



$$\left\langle V_{sky}^2 \right\rangle = \frac{R_L}{2} \int_{\Delta\nu} \int_{4\pi} B_\nu(\theta, \varphi) A_{eff}(\theta', \varphi') \sin\theta d\theta d\varphi d\nu$$



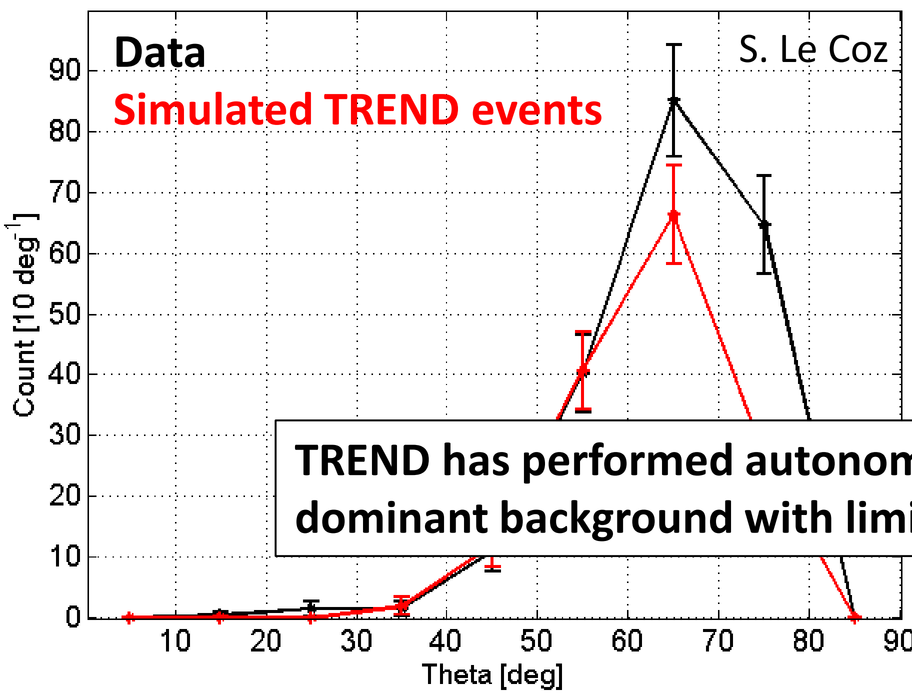
TREND calibration



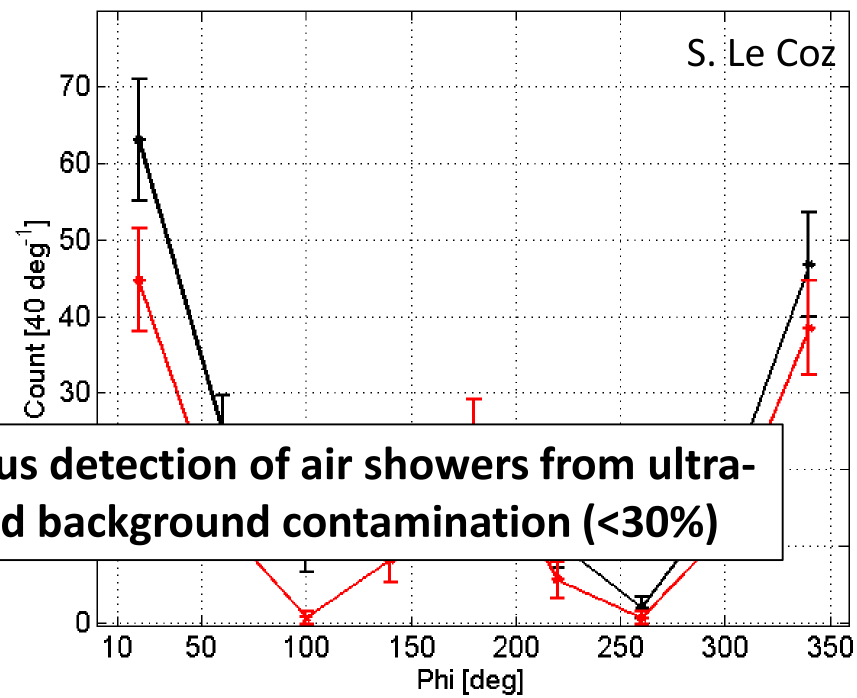
Results

- Simulated data set allows computing detector apperture:
  - $S_{eff}(E,\theta,\varphi) = S_{sim}(E,\theta,\varphi) * \frac{N_{det}(E,\theta,\varphi)}{N_{sim}(E,\theta,\varphi)}$ effective area [m²]
  - $App(E) = \iint_{d\Omega} S_{eff} \cos\theta \sin\theta d\theta d\phi$ apperture [m²sr]
- Event number during period Δt=80 days:
  - $N(\Delta t) = \int_E App(E) \frac{dN}{dE} dE * \Delta t$ with differential flux $\frac{dN}{dE} = K_0 E^{-\alpha}$ [$m^{-2}sr^{-1}s^{-1}$]
  - **N(80 days) = $\mathbf{177^{+49}_{-44}}$** (205 experimental candidates in the corresponding subset)

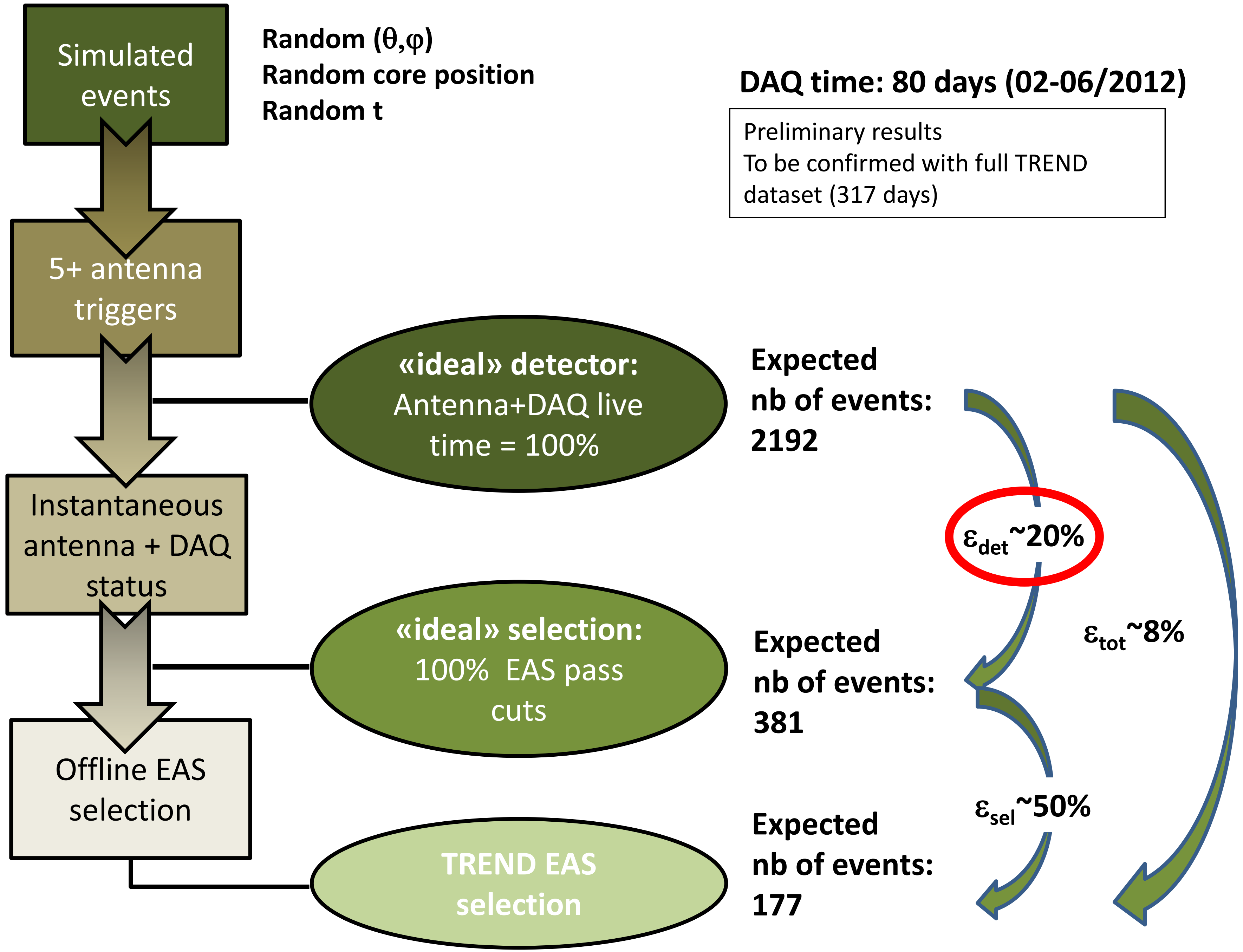
Zenith distribution



Azimuth distribution

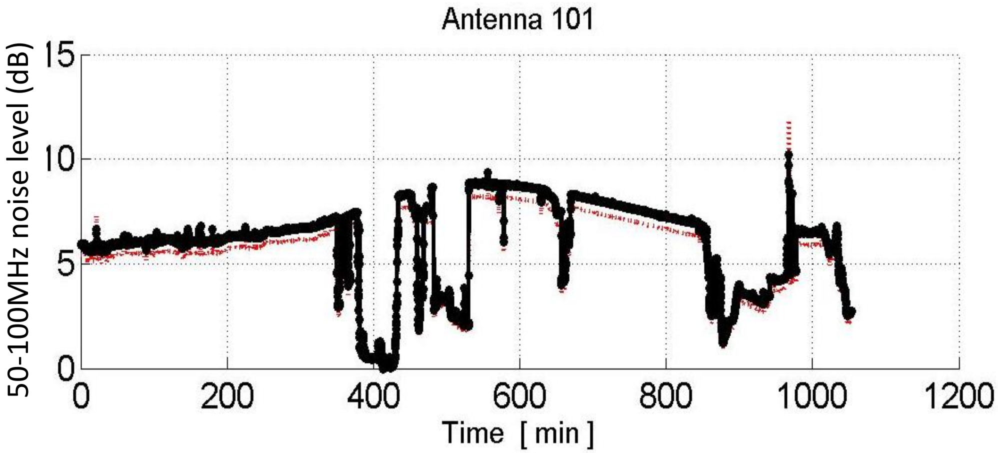


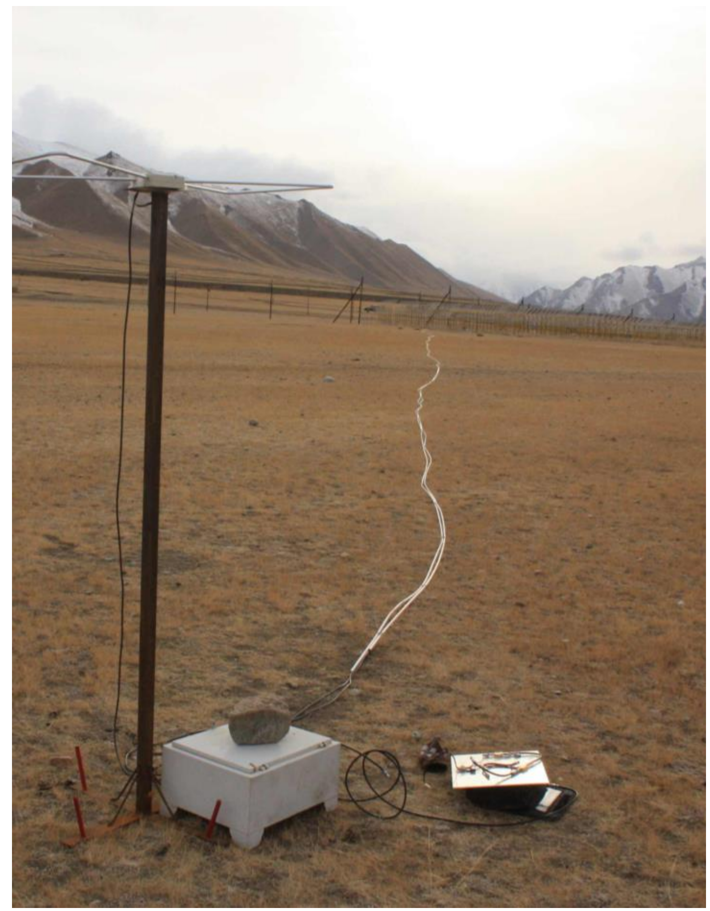
TREND has performed autonomous detection of air showers from ultra-dominant background with limited background contamination (<30%)


Simulated events
Random (θ,φ)
Random core position
Random t
DAQ time: 80 days (02-06/2012)
Preliminary results
To be confirmed with full TREND dataset (317 days)
5+ antenna triggers
«ideal» detector:
Antenna+DAQ live time = 100%
Expected nb of events: 2192
Instantaneous antenna + DAQ status
ε_{det}~20%
«ideal» selection:
100% EAS pass cuts
Expected nb of events: 381
ε_{tot}~8%
Offline EAS selection
ε_{sel}~50%
TREND EAS selection
Expected nb of events: 177

TREND issues

- «You get what you pay for»: **system reliability** questionnable
  - Sudden drops in gain
  - Aging (antennas, amplifiers, optical system, computers…)

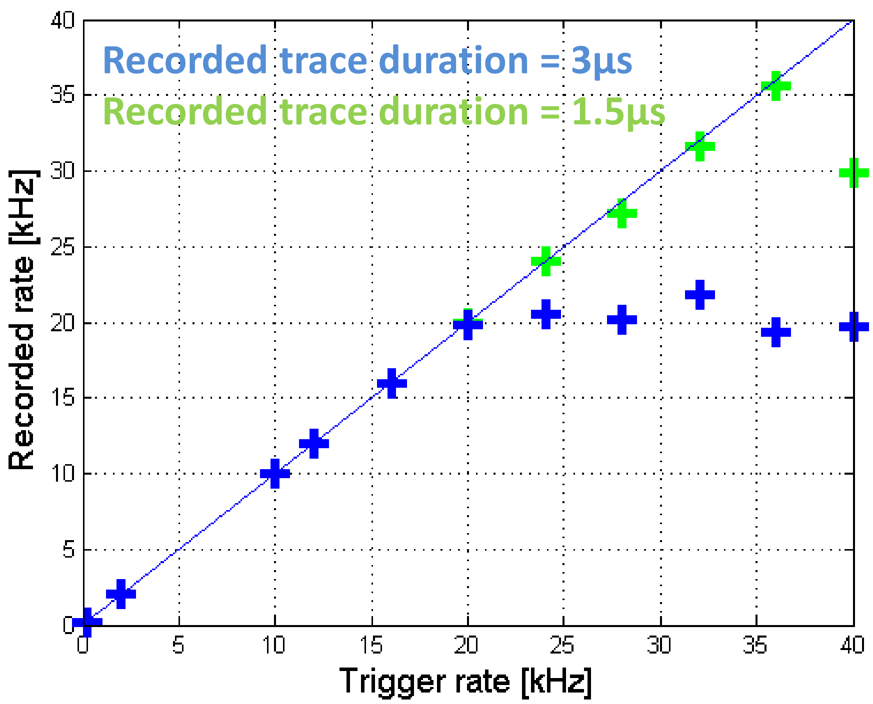


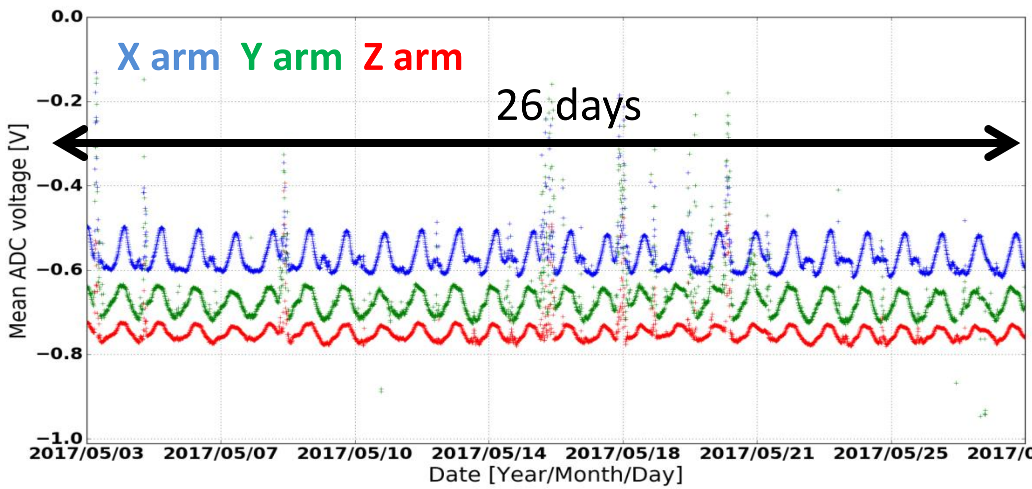


Next steps

- **GRANDproto35:** dedicated setup of 35 antennas deployed on the TREND site. Goal: optimized detection efficiency & air shower purity
  - Polarization measurement (3 arms antenna) brings additionnal tools for background rejection
  - Dedicated electronics & DAQ (developped at LPNHE) should allow ~100% live time.

  ➔ Expecting improved detection efficiency & background rejection compared to TREND.





Conclusion

- TREND accomplished its initial goal: performing succesfull detection & identification of air shower with an autonomous radio array. Paper in preparation.
- Limited detection efficiency & sample purity due to flows in TREND setup. Should be fixed on GRANDproto35 (starting early 2018), a first step towards GRAND [Zilles, Friday PM].

谢谢

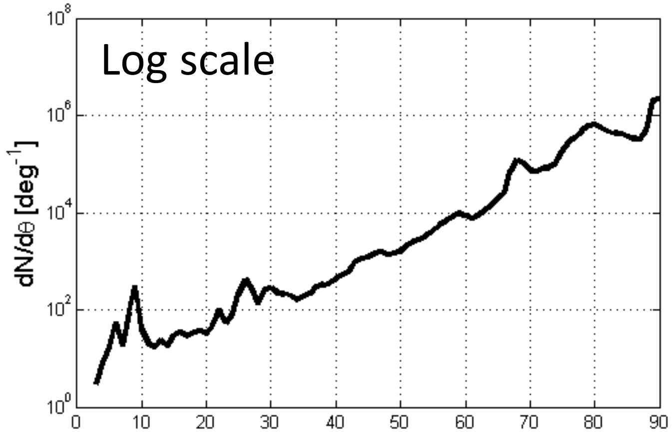
Cut efficiency

Cut	% survival	N_{coincs} final	*% survival [simu]*	*N_{coins} [simu] (not E weighted)*
« 50Hz » cut	8%	6.3 10^7	*82%*	*1526*
Pulse duration	46%	2.9 10^7	*86%*	*1312*
Multiplicity > 4	51%	1.4 10^7	***80%***	*1050*
Valid reconstruction	67%	1.0 10^7	*99%*	*1040*
Radius > 3000m	35%	3.4 10^6	*95%*	*988*
$\Theta < 80°$	30%	1.0 10^6	*98%*	*968*
Trigger pattern/ Extension	32%	3.3 10^5	*88%*	*855*
Neighbourgs (direction)	**0.3%**	1440	*85%*	*725*
Neighbourgs (time)	40%	**574**	*92%*	***668***

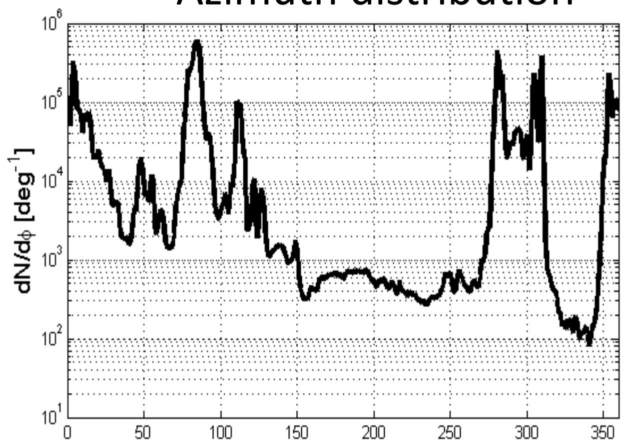
Simulated EAS selection cuts survival rate: 37% (46% if multiplicity cut excluded)

Radio background

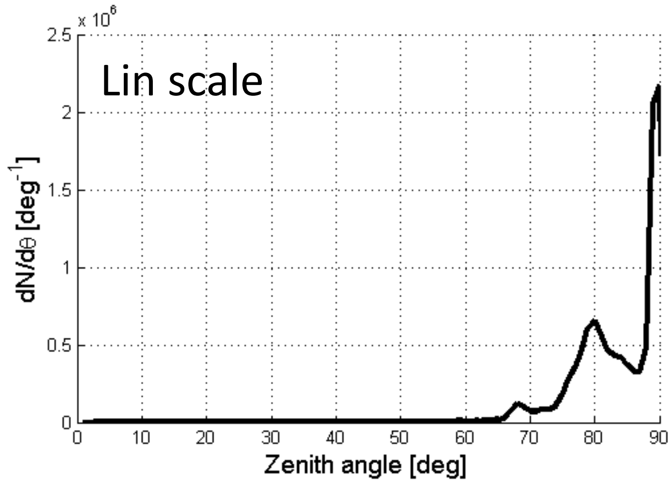
Zenith distribution

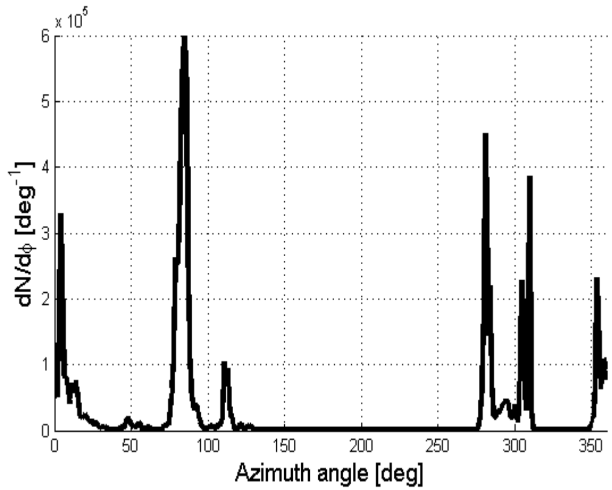


Azimuth distribution



North West South East





- Here selecting plane wavefronts only (curvature radius>500m)
- Most events coming from specific directions (N,E,W) along horizon (static noise sources)

Direction distribution

- Shapes of zenith and azimuth distributions of **experimental radio candidates** and **simulated EAS** are compatible.
- Excess of experimental data at large zenith angles & towards North & West (⇔ standard background sources)

➔ Excess most likely corresponds to background events passing cuts.

➔ **Still to be refined, but already TREND has performed autonomous detection & identification of EAS, sample purity ~ 70%.**