Autonomous detection of air showers with the TREND-50 setup

Genesis & status of the TREND project

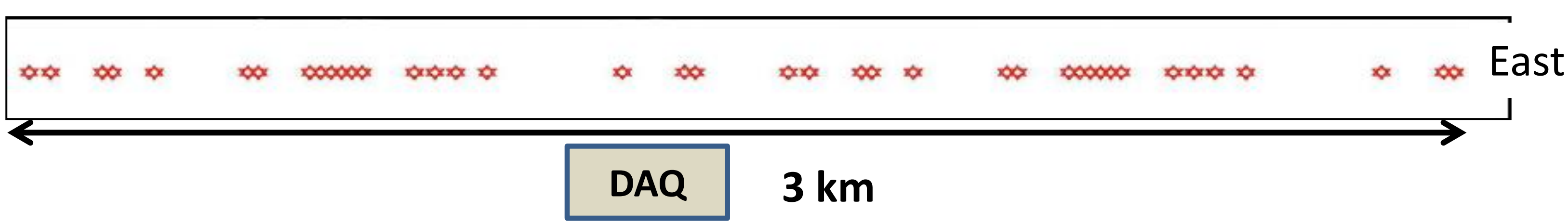
Autonomous radio-detection of air showers

Jianli Zhang(NAOC,CAS) & Olivier Martineau-Huynh(LPNHE) for the TREND Collaboration

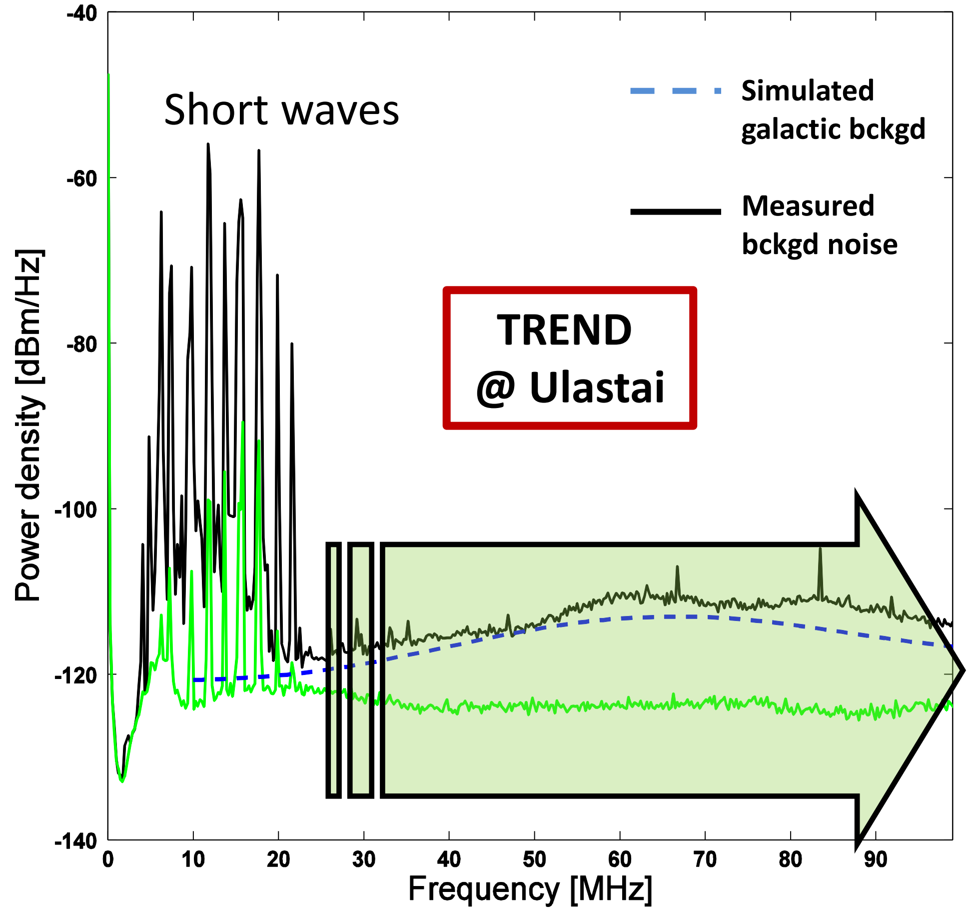
FCPPL Heifei 8-10 April 2015

The 21cm array

Radiointerferometer for the study of the Epoch of Reionization (**Wu XiangPing, NAOC**) completed in 2007.



The TREND site



- Ulastai, Tianshan mountains, XinJiang autonomous province (2650m asl)

The TREND « sales strategy »

- **Autonomous** Extensive Air Shower(EAS) radio detection & identification as a key issue in the persepective of a giant radio array for EAS.
- Radio in R&D phase: need to explore different technological options.
- TREND as an opportunity:
  - low elm bckgrd @ Ulastai
  - 21CMA setup to be used for ~free (for France)!
  - Large radio-setup instrumental to improve our understanding of EAS radio info
- Long term plans: neutrino telescope

The TREND contributors

- China: CAS
  - NAOC: **<u>Wu XiangPing</u>**, Thomas Saugrin (2009-2012), Zhao Meng (computing), Deng JianRong*, Zhang JianLi**, Gu Junhua**
  - IHEP: **<u>Hu HongBo</u>**, Gou QuanBu, Feng Zhaoyang**, Zhang Yi**

- France: CNRS-IN2P3
  - LPNHE: OMH, Patrick Nayman***, Jacques David***
  - SUBATECH: Pascal Lautridou (2008-2013), Daniel Ardouin (2008-2010), Didier Charrier (radio antennas)
  - LPC: Valentin Niess
  - CC: Fabio Hernandez (computing)

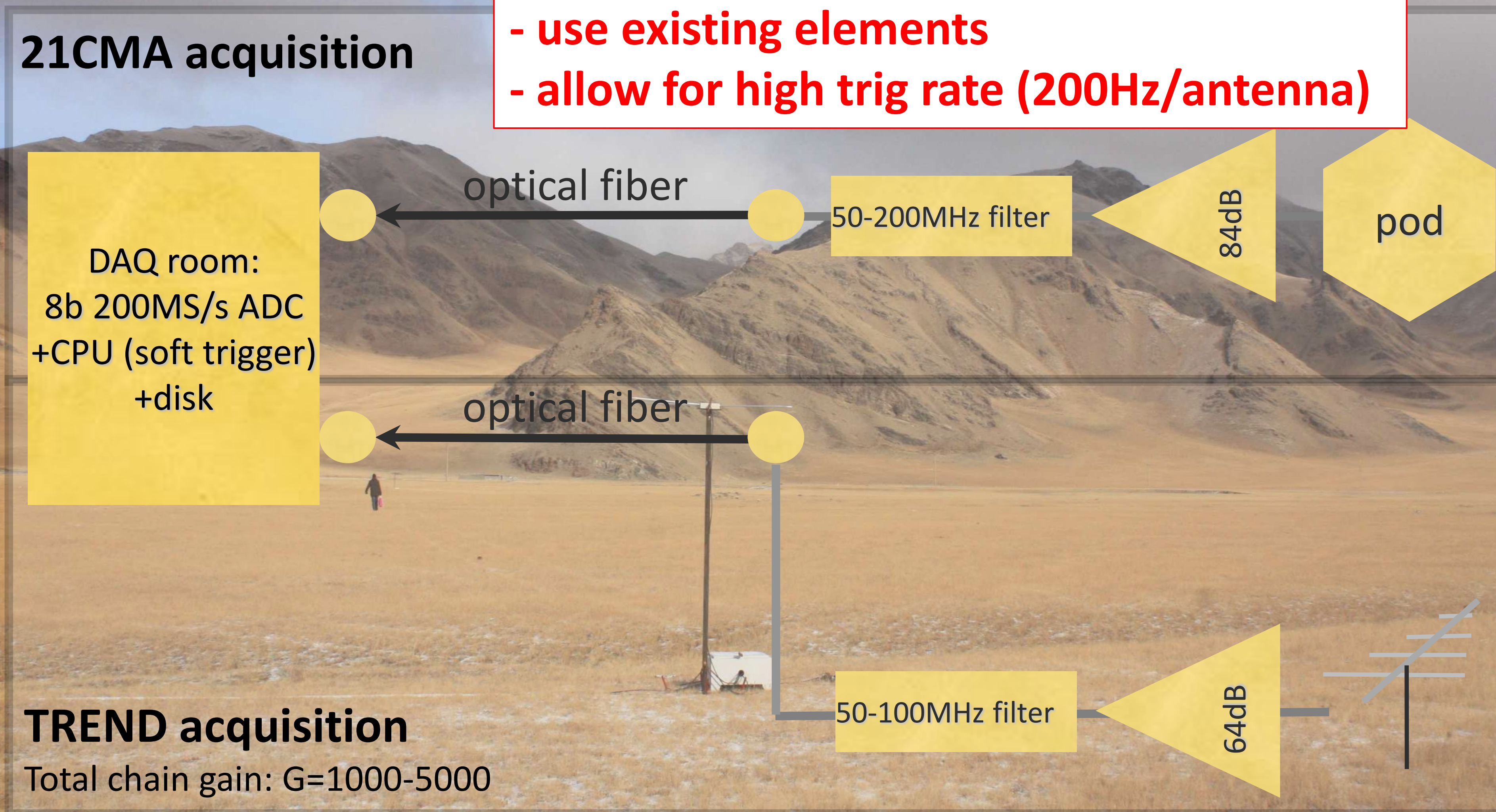
*: after 2010
**: after 2012
***: after 2014

Nearly everybody at a small fraction of time on TREND!!!

Extensive Air Shower(EAS) autonomous radiodetection
at the
Tianshan Radio Experiment for Neutrino detection
(January 2009 - June 2014)

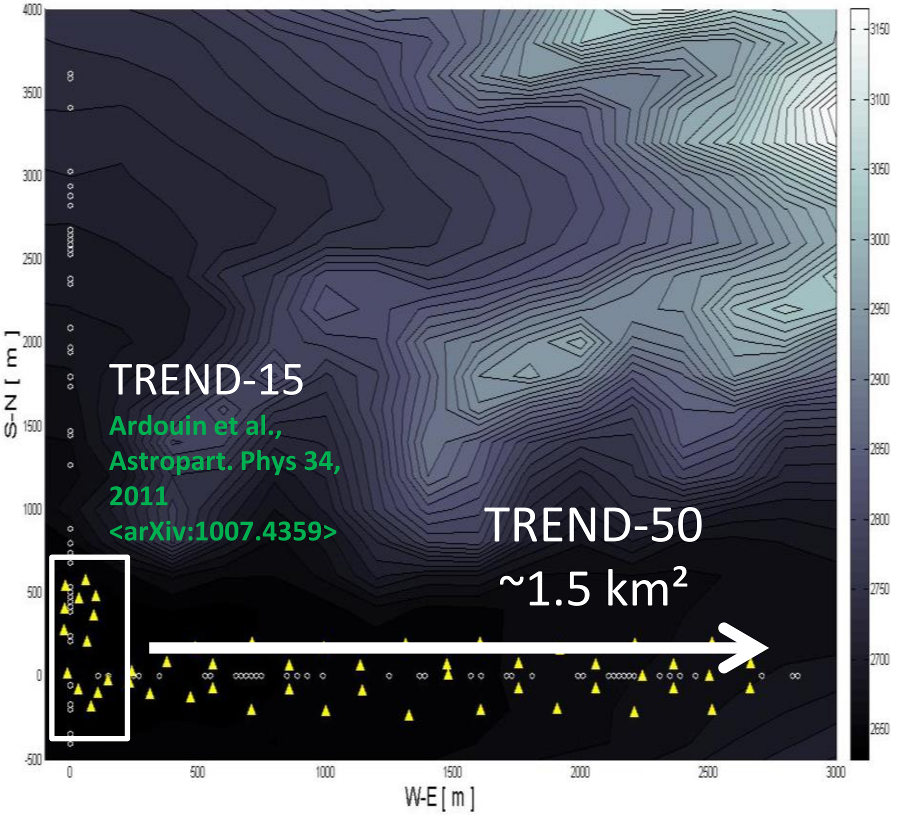
TREND DAQ

Driving concepts:
- use existing elements
- allow for high trig rate (200Hz/antenna)



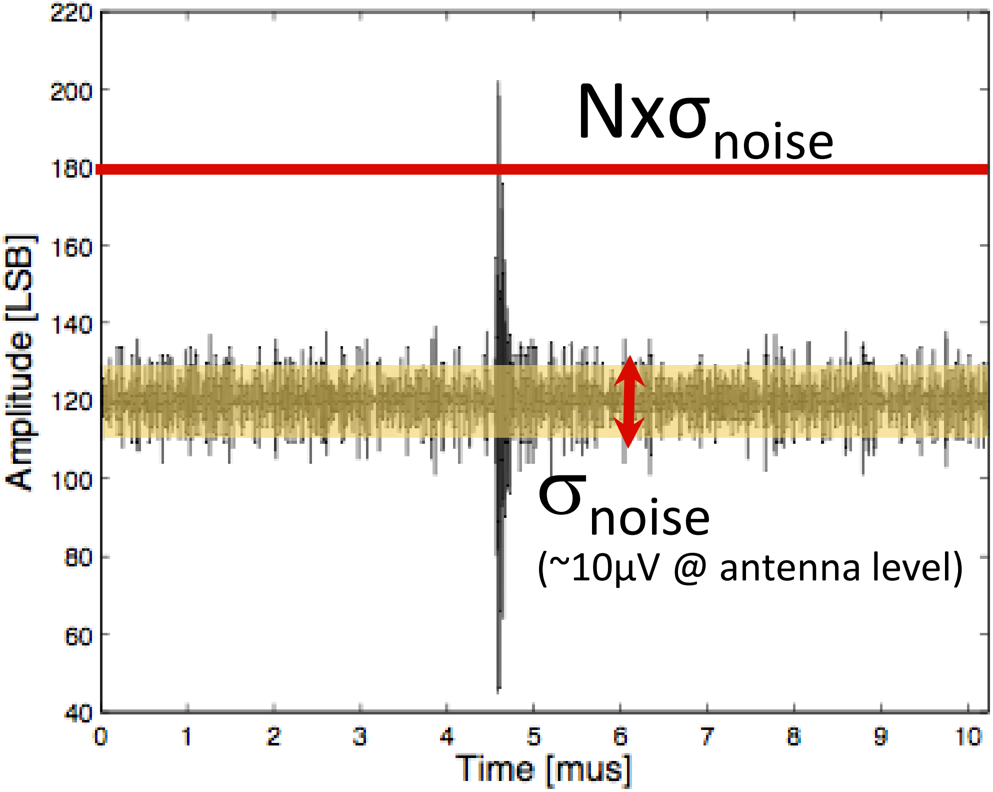
The TREND-50 setup

- 50 monopolar «Butterfly antennas» deployed in summer-automn 2010 over a total surface ~1.5km². Average antenna step = 150m.
- Stable operation between January 2011 & June 2014.
- EW orientation in 2011-2012, then NS.



TREND DAQ

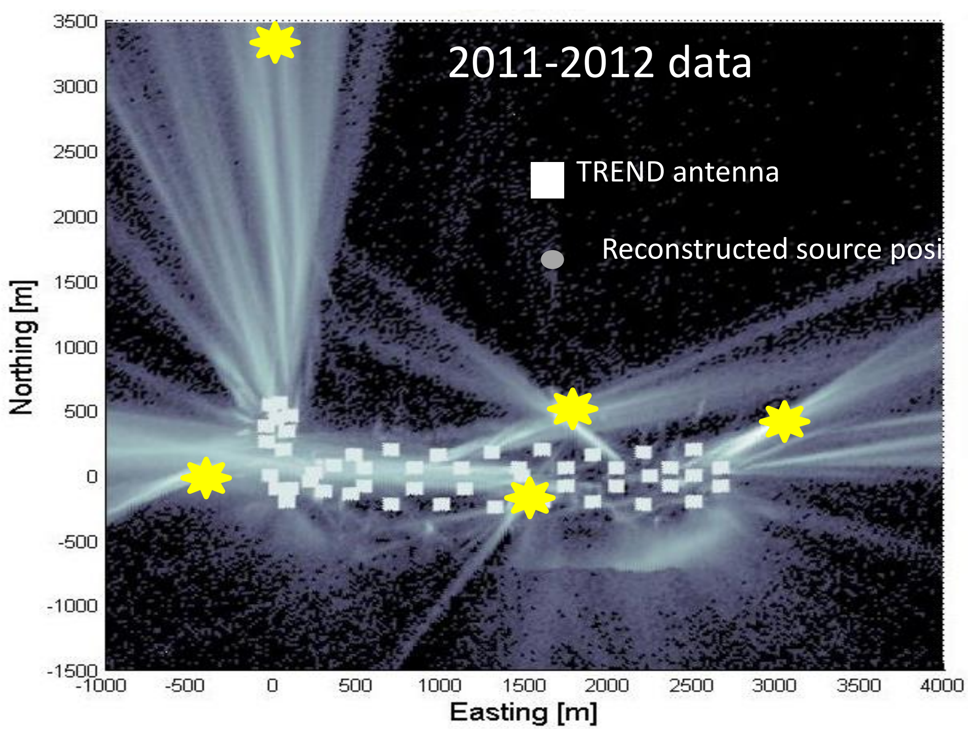
- Analog radio signal transfered through optical fiber to DAQ room.
- On the fly parrallel digitization at computer level (200MS/s, 8bits).
- soft trigger if antenna amplitude > N$x\sigma_{noise}$ (N in 6-10)
- 1024 samples (≈5 μs) written to disk for all triggered antennas .
- For coincident triggers: offline signal direction reconstruction by triangulation
  - Plane wave treatment: direction (Θ, ϕ)
  - Point source treatment: position (x, y, z)



TREND DAQ driving concept: DAQ designed to accept large trigger rate (up to 200Hz/antenna). Candidate selection performed through offline treatment.

TREND trigger performances

- T0 rate <100Hz for 90% of the time on all antennas.
- **DAQ efficiency ~ 70%.**
- Large trigger rate variations at all time scales on all antennas: **«noise bursts»**
- **Noise is correlated between antennas: common (physical) origin.**
- Time delay between consecutive events & point reconstruction points dominantly towards **HV sources.**



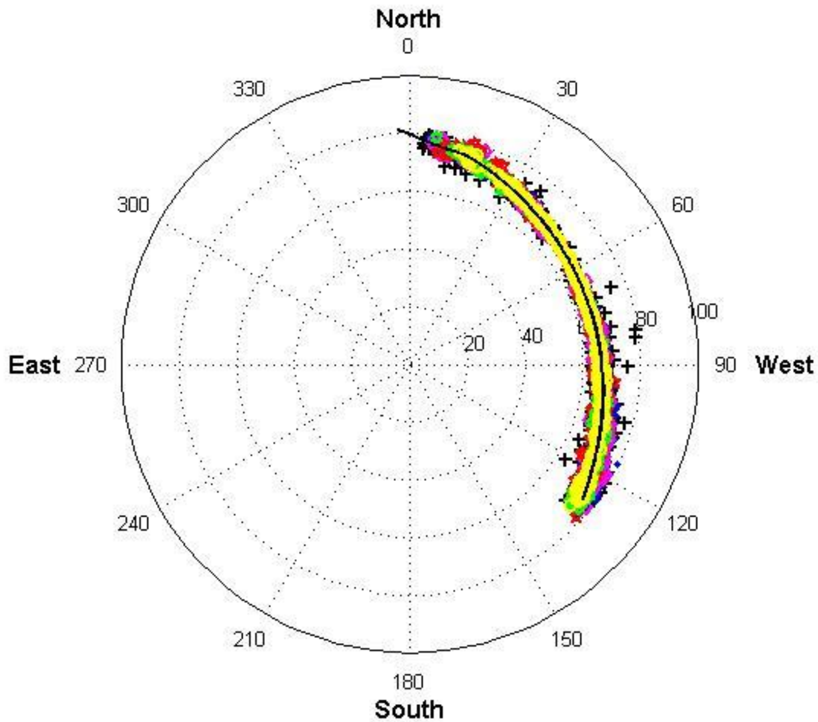
<u>2011-2012 data:</u>
317 DAQ days analyzed

3.7 10^9 triggers recorded
2.4 10^8 coincidences
<u>~10Hz</u> average coinc rate over whole array

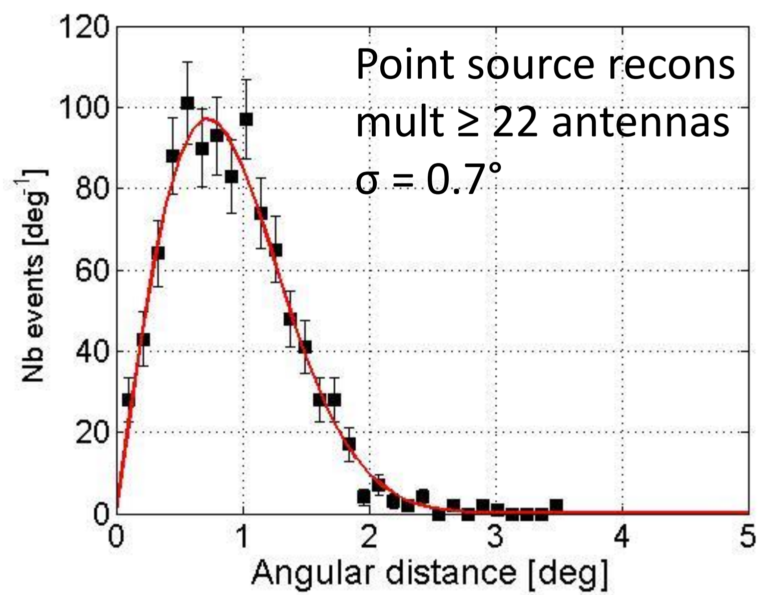
(~20 EAS/day expected)

RADIO PERFORMANCES: DIRECTION RECONSTRUCTION

- **Plane track reconstruction :**



- 3037 events in 4 minutes
- Θ > 60°
- Max multiplicity: 40

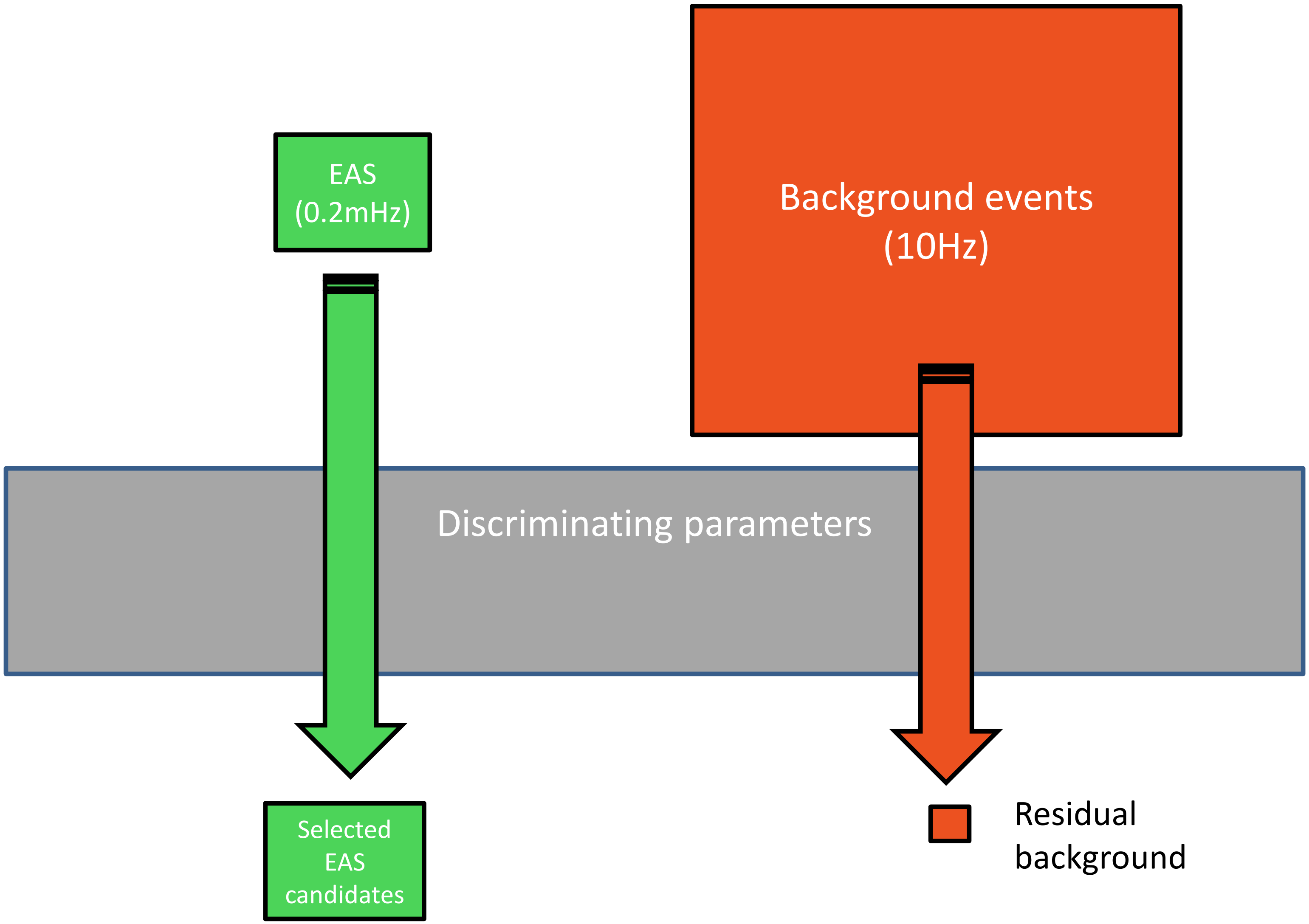


Total angular resolution <1.5° on the track (and improves with smaller zenithal angle)

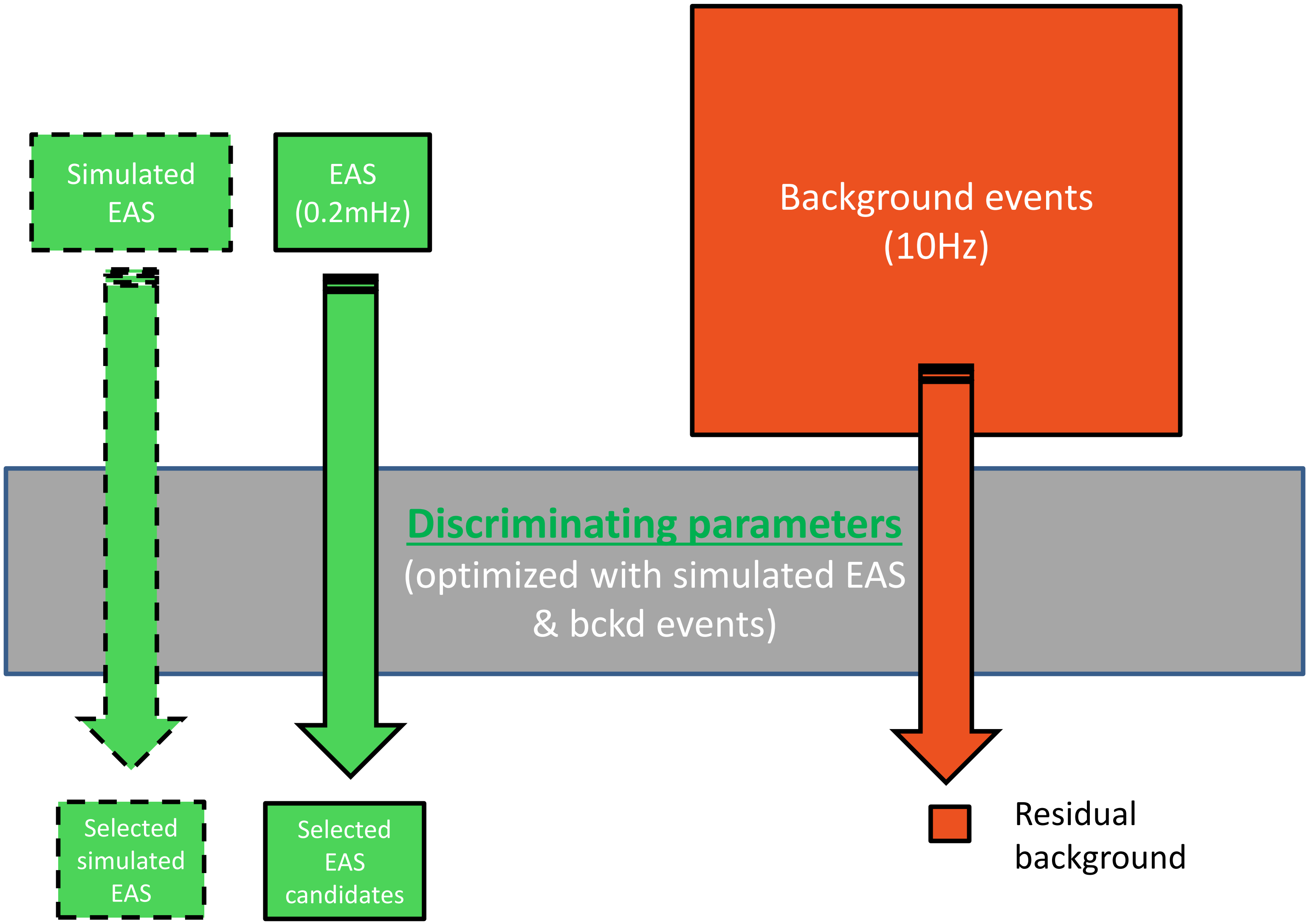
Estimated antenna trigger timing error: ±10ns

TREND-50
Extensive Air Shower(EAS) search

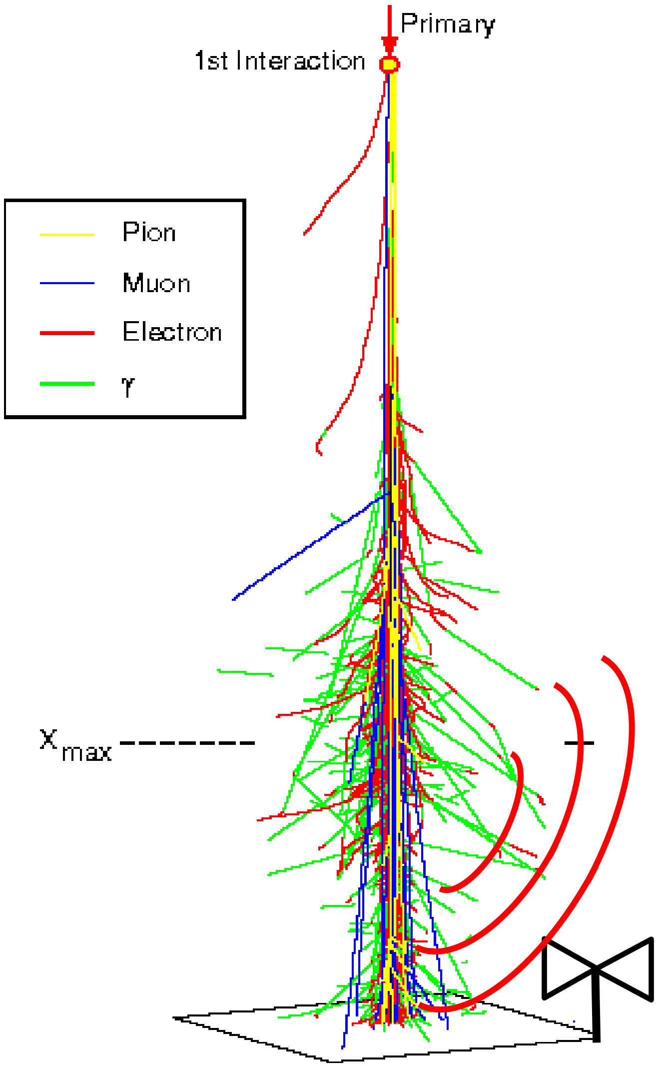
EAS identification: principle



EAS identification: principle



EAS simulation



p@ E in [3 10^{16} – 3 10^{17}] eV with isotropic sky distrib & random core position

Shower dvlpmt (CONEX)

elm emission (EVA)

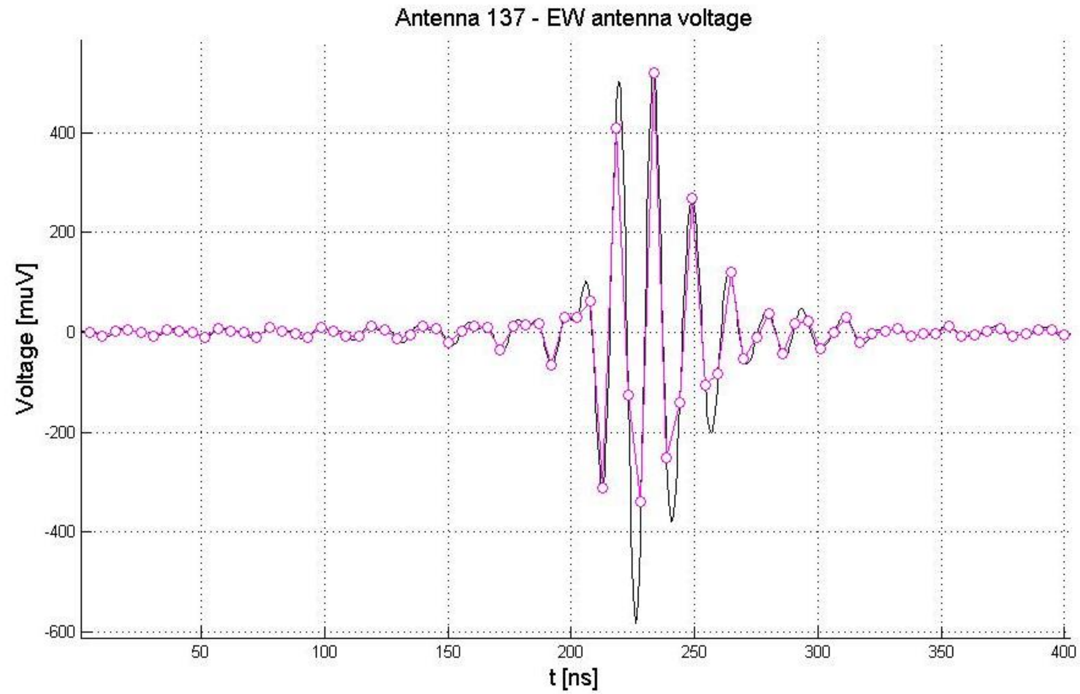
Slow!

Antenna response (NEC2)
(if distance<800m)

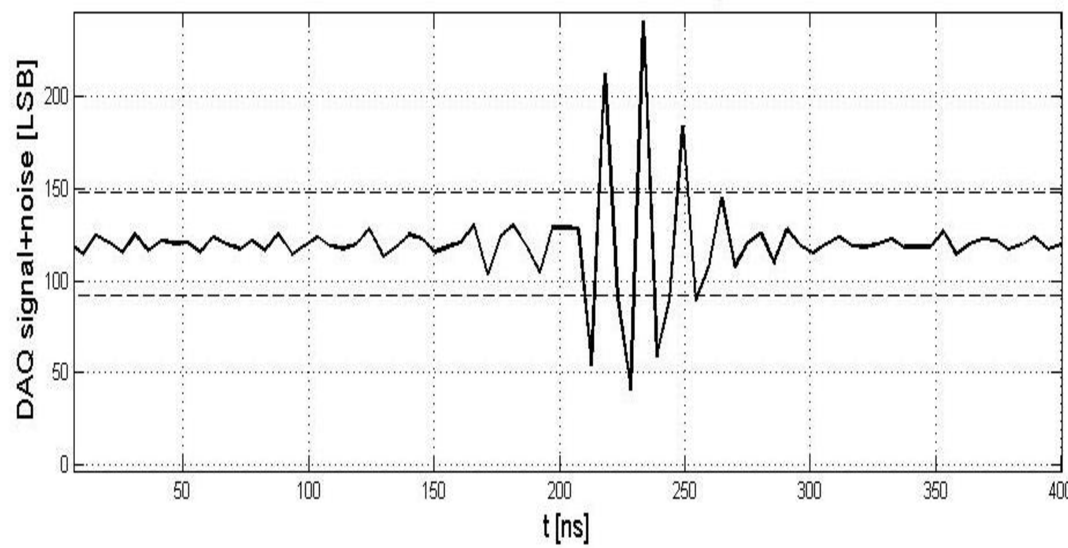
400 showers/E x 20 core positions x 15 antennas
120’000 voltage computations ⇔ **240’000h CPU**
Using **DIRAC+VO France-Asia (IHEP, KEK, CC-IN2P3 & LPNHE)**

EAS simulation

- Simulated antenna signal (—) digitized @ 200MS/s (**o**)

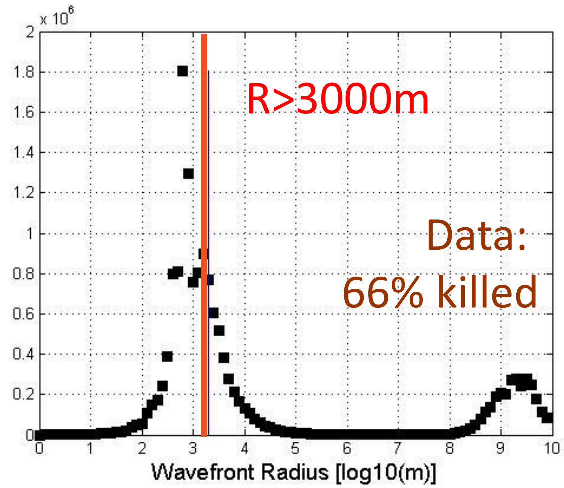


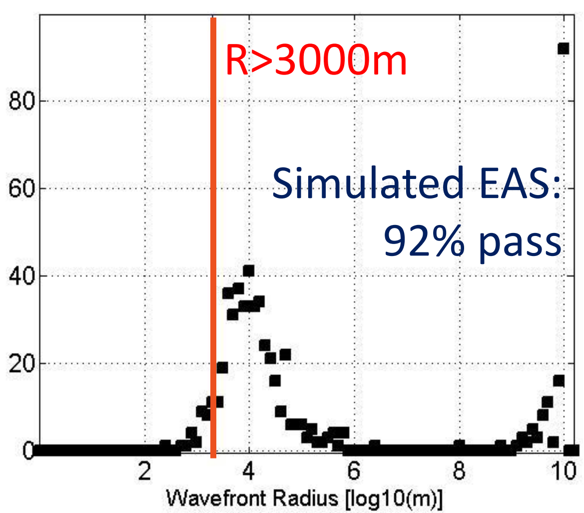
- V_{simu} x G + noise (—) using experimental (G, noise)
- Applying TREND trigger condition with th = $8\sigma_{noise}$ (---)
- Shower considered detected if 5+ antennas triggered.
- Standard datat treatment & reconstruction.



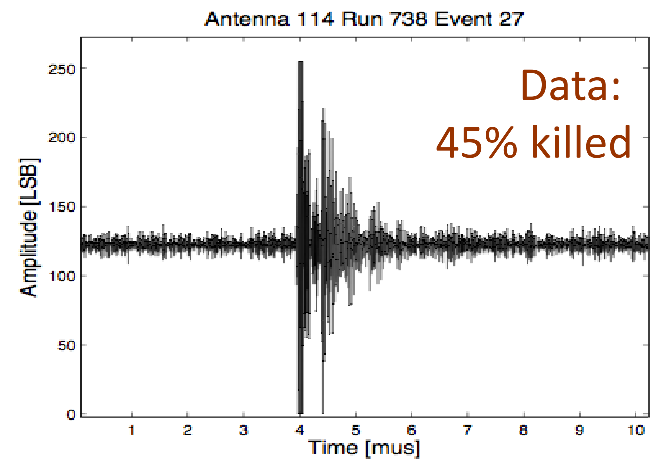
Discriminating parameters

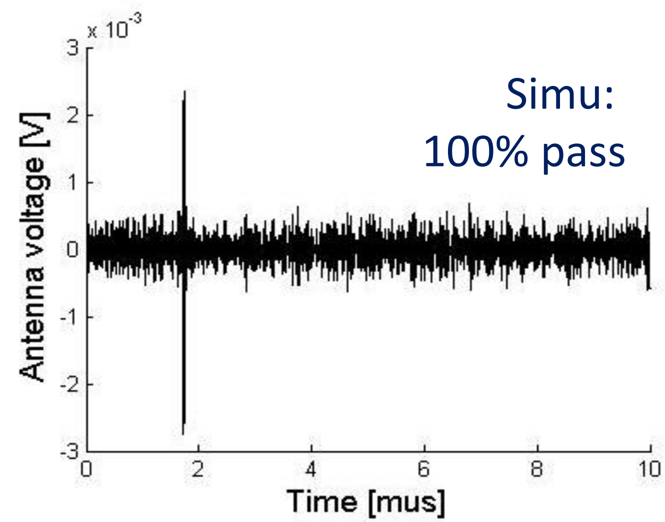
- Spherical wave recons: point source reconstruction of backgrd sources close to array, EAS more distant.





- Signal shape: prompt signal for EAS

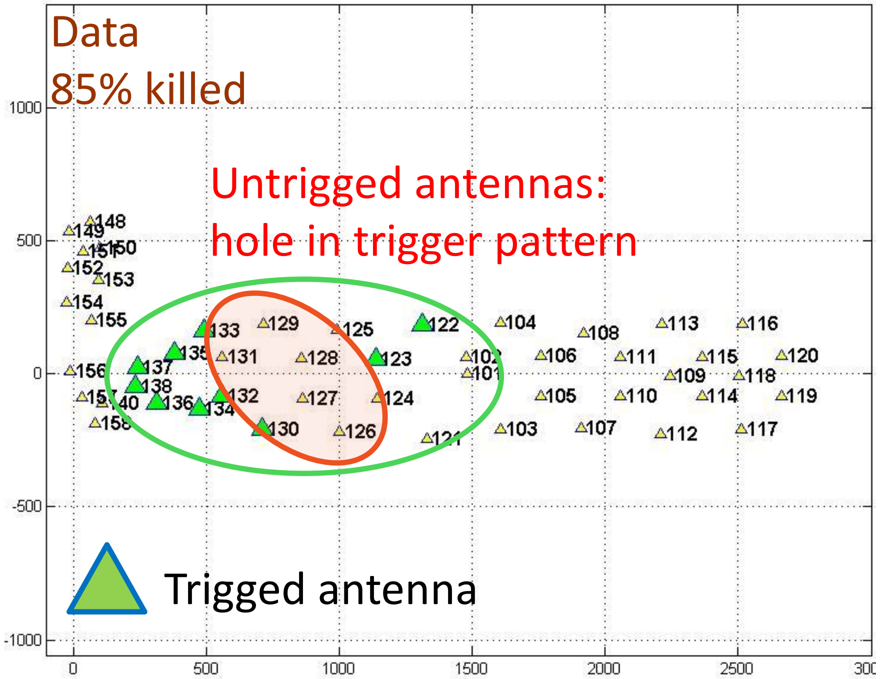


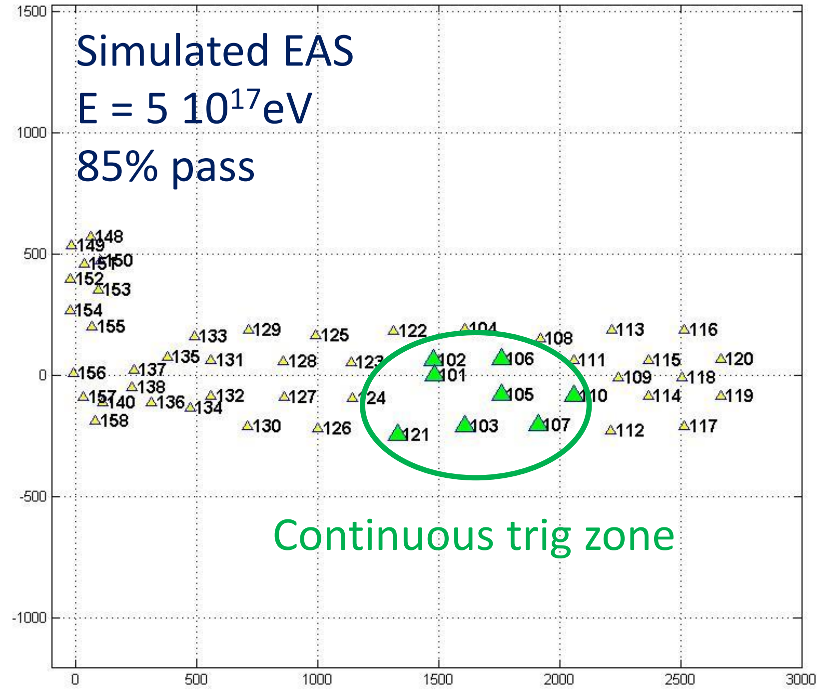


Discriminating parameters

- Array trigger pattern should be continuous for EAS

(E-field linear polarization at 1st order, random for bckgd)

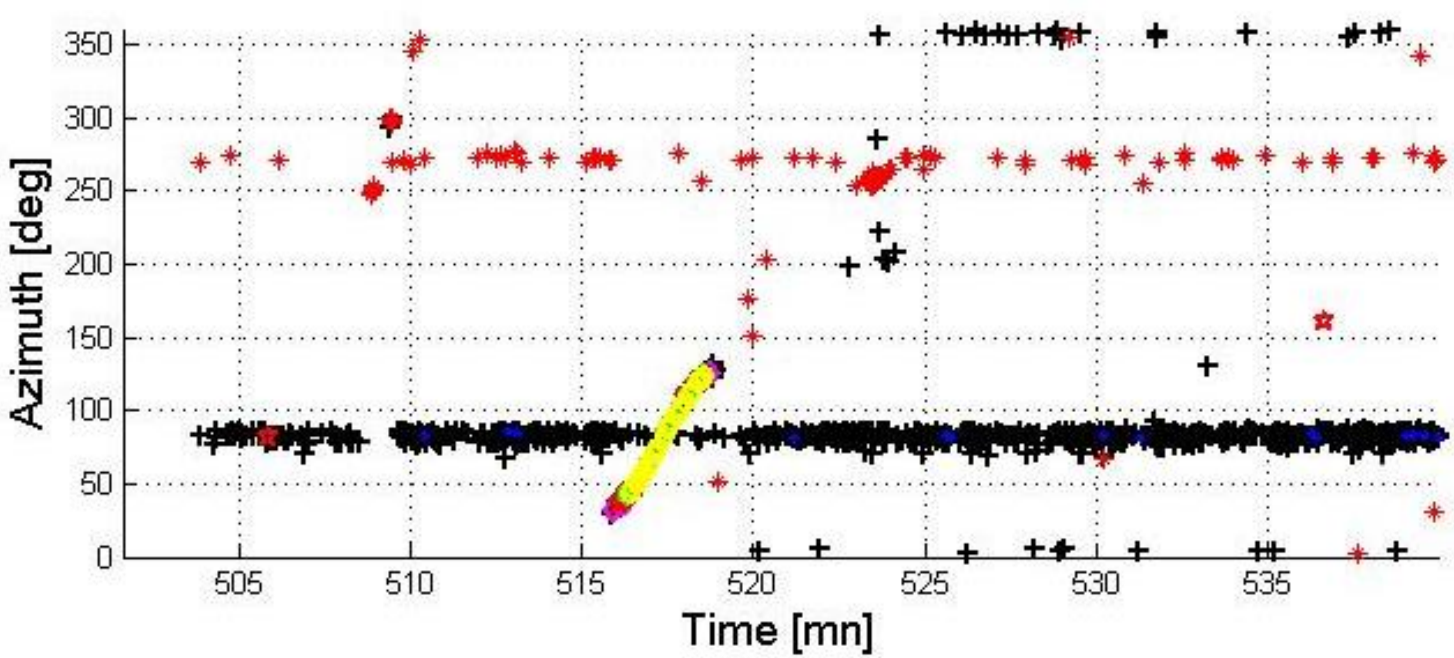




Limited array size + monopolar antennas
(+ system unreliability) reduce cut efficiency.

Environment cuts

- Bckgd events strongly correlated in time & space



- Consecutive coincs: reject EAS candidate if 1+ coinc with 4+ antennas in common within 30s.
- Same direction events: reject EAS candidate if 1+ coinc with 2+ antennas in common and $|\Delta\varphi|<10°$ within 10 minutes.

Cut efficiency:

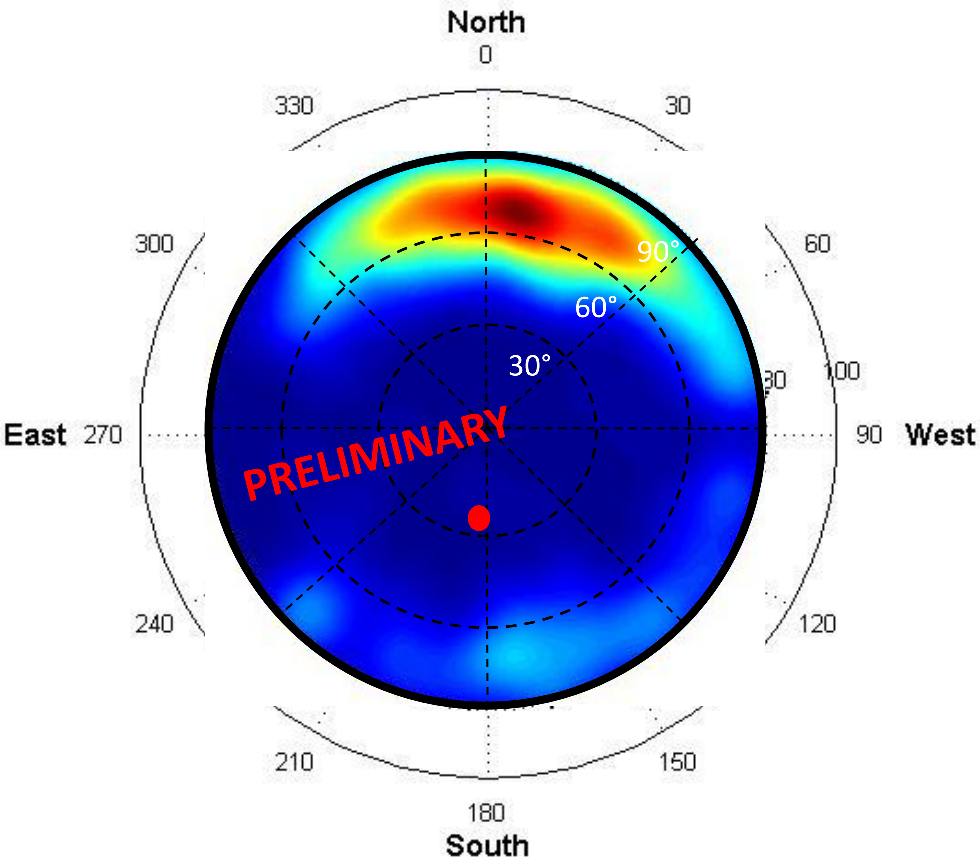
from 2.4 10^8 to 465 events

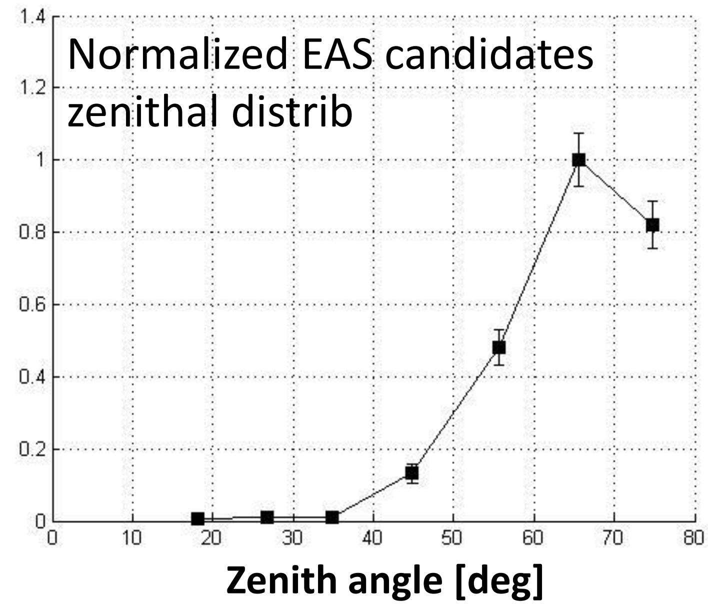
Cut	% survival	N_{coincs} final	Simu % survival
« 50Hz » cut	24%	5.9 10^7	To be determined
Pulse duration	56%	3.3 10^7	100%
Multiplicity > 4	57%	1.9 10^7	-
Valid direction reconstruction	79%	1.5 10^7	100%
Radius > 3000m	33%	5 10^6	92%
Θ < 80°	14%	7 10^5	/
Trigger pattern/ Extension	15%	10^5	85%
Neighbourgs (direction)	**3%**	2600	To be determined
Neighbourgs	18%	465	To be determined

No cut is related to wave (absolute) arrival direction.

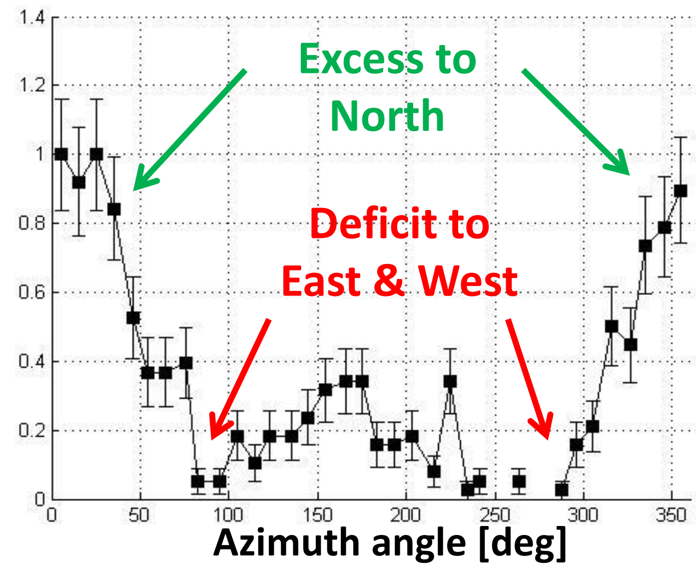
TREND EAS candidates

2011-2012 data
(EW polar, 317 DAQ days)
465 candidates



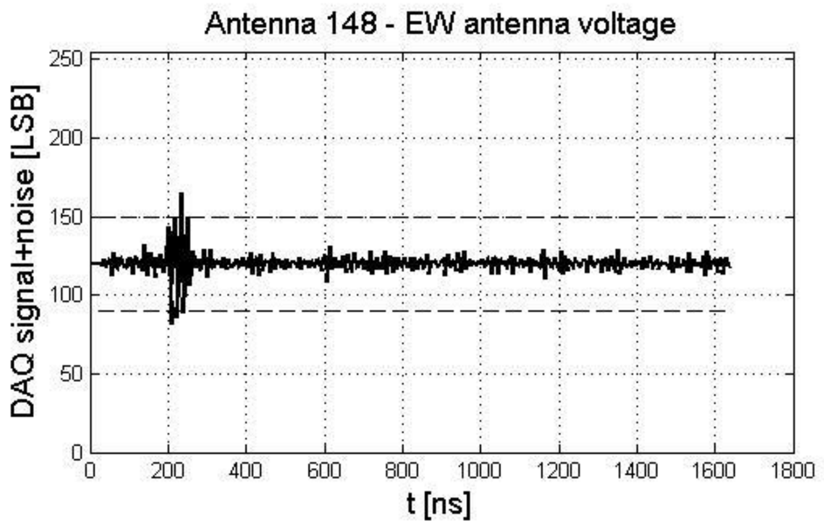


Normalized EAS candidates
azimuthal distrib

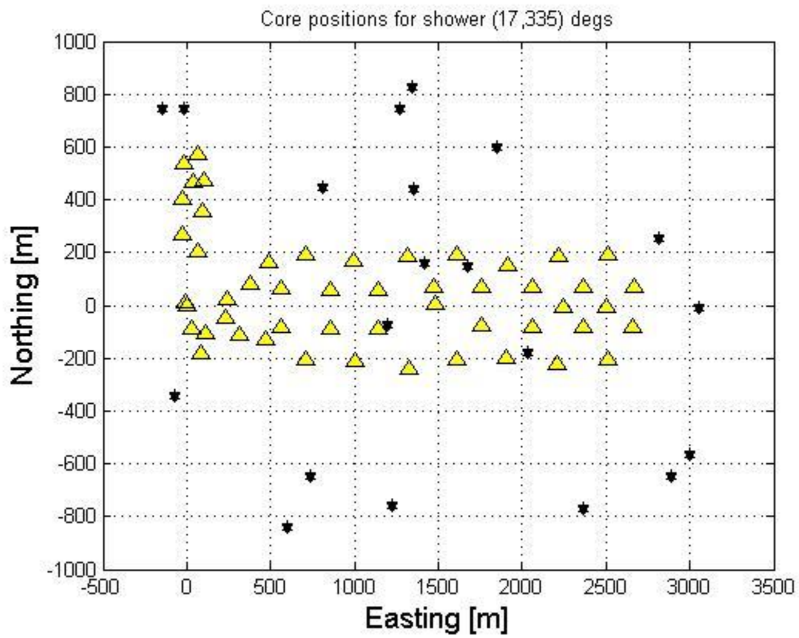


Simulated skymap

- For given direction (θ, φ): 20 random x_{core} with min dist to array < 800m.
- For given shower geometry (θ, φ, x_{core}):
  - check if antennas signals are above threshold ($8x\sigma_{noise}$)
  - If OK for 5+ antennas, tag this geometry as 'trigged'.
- For each direction (θ, φ), compute ratio $N_{triggered}/N_{simulated}$ ($N_{simulated}$ = 20 in principle)

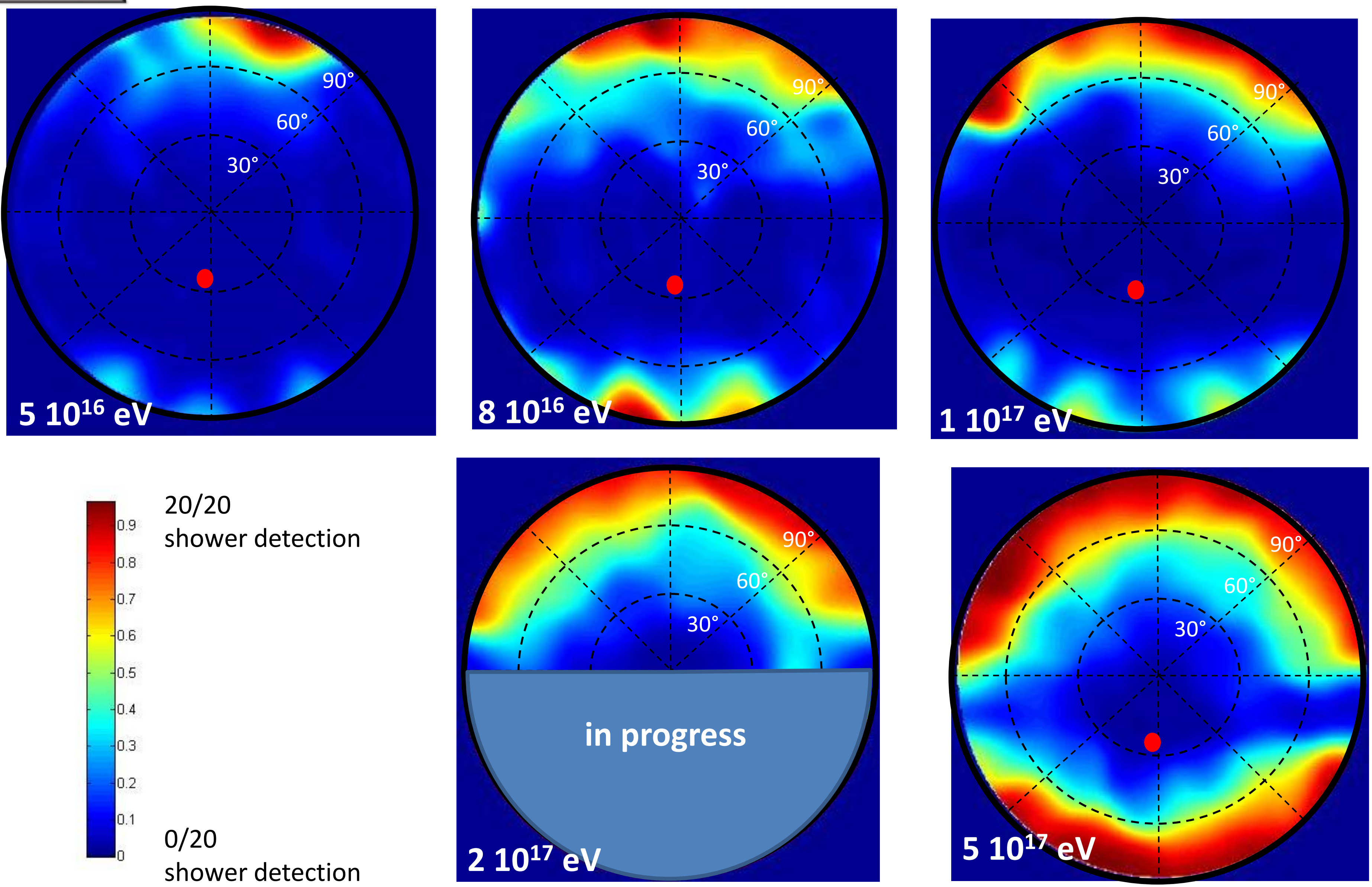


Simu voltage x calib + noise



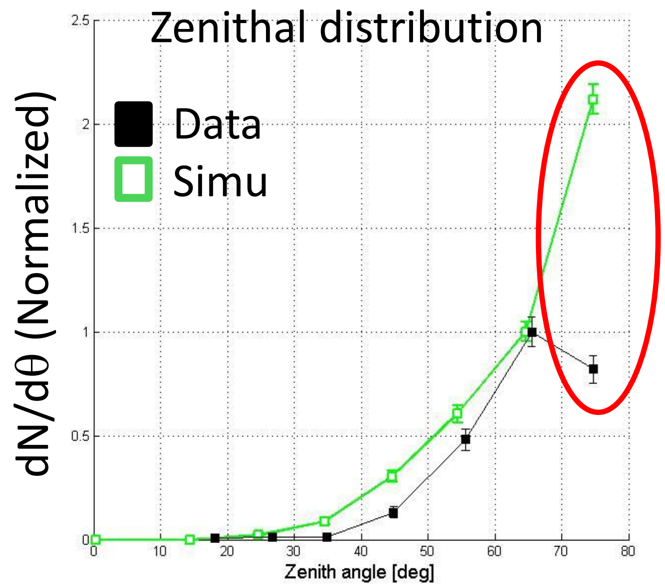
Simulated sky maps

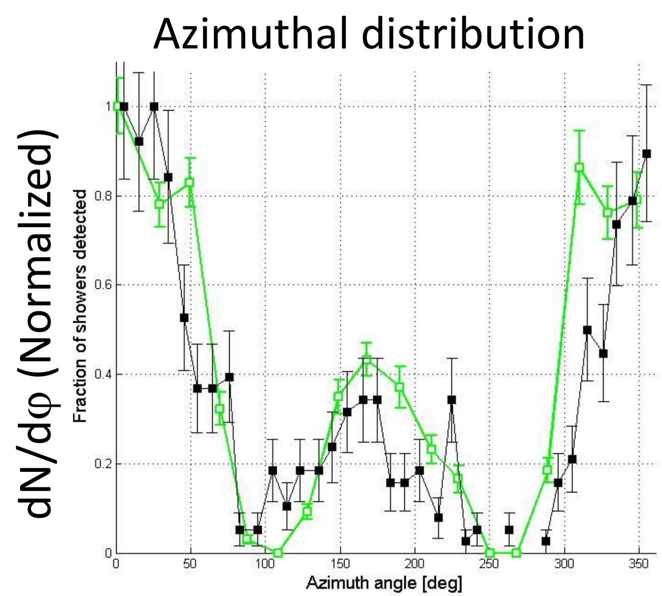
(Zhang Jianli & Gu Junhua)



Data-Simu comparison

- Combining 8.10^{16} & 10^{17}eV simulated data sets.
- Comparable zenithal, azim and multiplicity distributions (except for very inclined showers: reflexion issues or cuts?)
- Expected nb of events for threshold = 10^{17}eV: ~6000 in 317 days before analysis cuts. 465 observed… **Detection efficiency <10% ?!**





TREND-50 summary

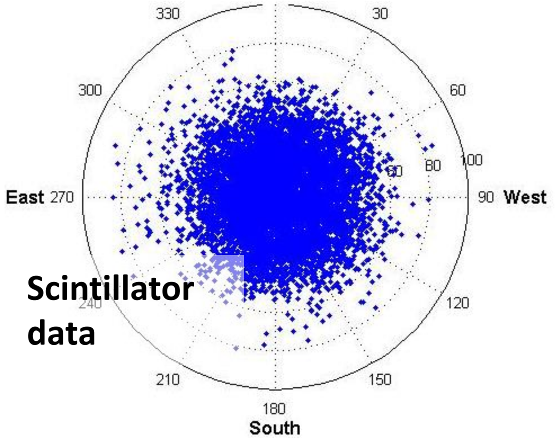
- **Initial goal reached**: autonomous radio detection and identification of EAS with limited bckgd contamination (<~ 20%) thanks to low DAQ dead time.
- Limitations:
  - Low detection efficiency (set-up layout & stability)
  - Environment cuts kill detection efficiency when bckgd rises.
  - Event-by-event discrimination not possible.
  - Physics output with these data questionnable.
- **Larger array** with more stable detection chain would surely perform better…

GRAND

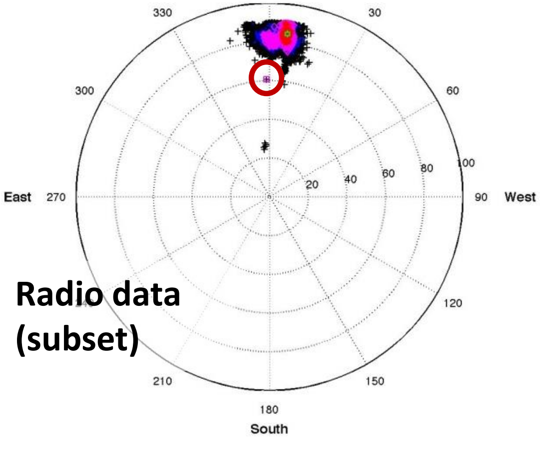
TREND early days (2009-10)

- **2009: 6 log periodic antennas : reconstruction algorithm development + autonomous trigger proof of principle.**
- **2010: 15 log-periodic antennas + 3 scintillators: independant trigger & analysis of scint data (EAS) & radio data (EAS radio candidates).**

Reconstruction of 3-fold scintillator coincidences ≡ EAS



Selection of radio EAS candidates with dedicated algorithm



Some radio EAS candidates are coincident with scintillator coincidences + direction recons match!

N_{ants}	θ_{radio}	θ_{scints}	φ_{radio}	φ_{scints}
4	61±3	67±5	359±2	3±4
4	52±1	49±3	195±2	191±4
5	42±1	36±3	55±4	56±5
4	45±1	49±3	12±1	10±5
7	56±2	53±4	323±2	331±5

First EAS identification with autonomous radio array

Ardouin et al., Astropart. Phys 34, 2011 <arXiv:1007.4359>