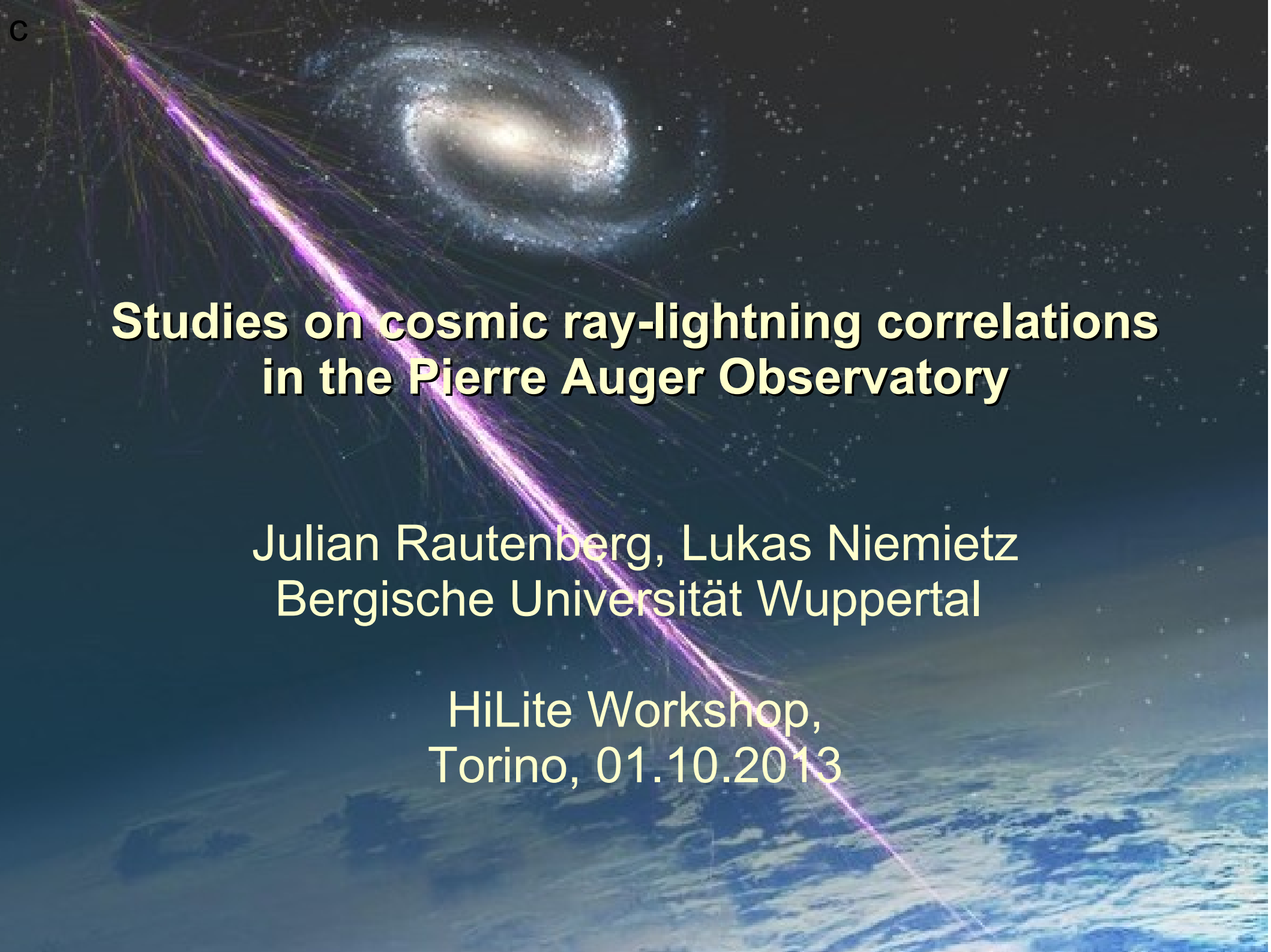
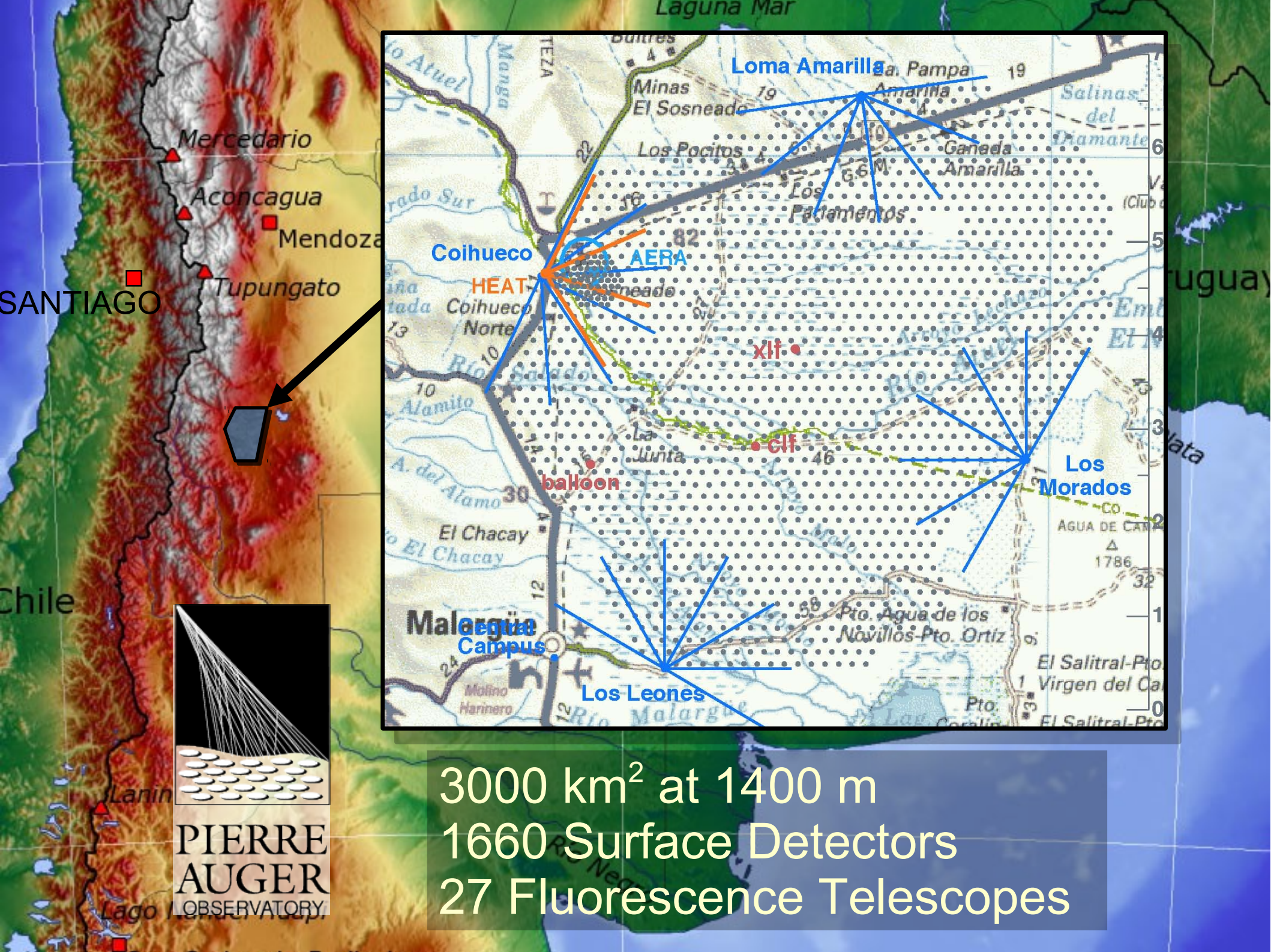


Studies on cosmic ray-lightning correlations in the Pierre Auger Observatory

Julian Rautenberg, Lukas Niemietz
Bergische Universität Wuppertal

HiLite Workshop,
Torino, 01.10.2013


Laguna Mar
Mercedario
Aconcagua
Mendoza
Tupungato
SANTIAGO
Chile
Lanin
Lago
Loma Amarilla
Minas
El Sosneado
Los Pocitos
Ganeda
Amarilla
Los
Patamentos
Coihueco
AERA
HEAT
Coihueco
Norte
xlf
clf
balloon
La
Junta
Los
Morados
El Chacay
Malargüe
Campus
Los Leones
Pto. Agua de los
Novillos-Pto. Ortiz
Molino
Harinero
PIERRE
AUGER
OBSERVATORY
3000 km^2 at 1400 m
1660 Surface Detectors
27 Fluorescence Telescopes

Autonomous Particle Detector

Communication-antenna

GPS antenna

Electronic cover

Solar panel

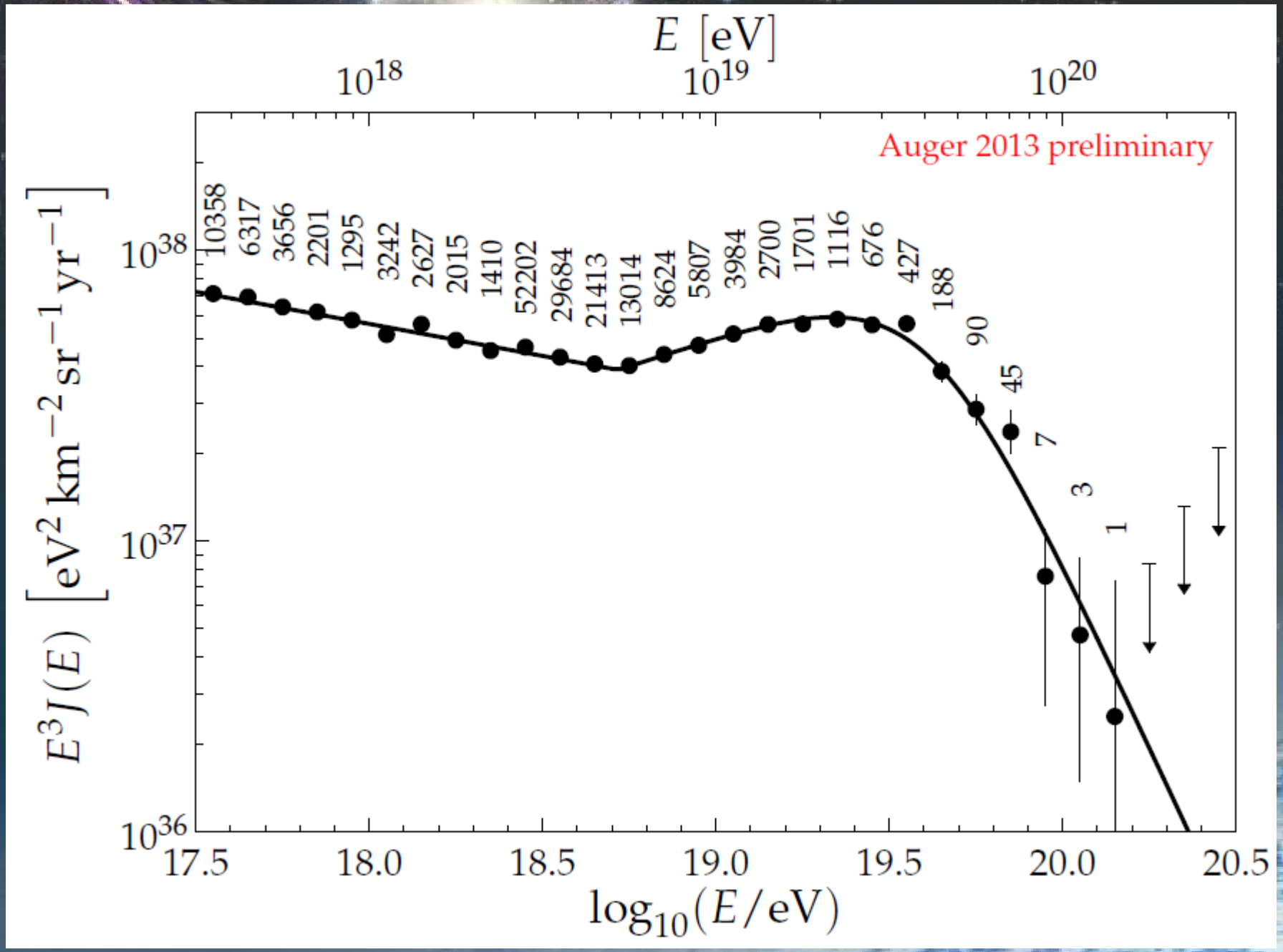
Battery

EZRA

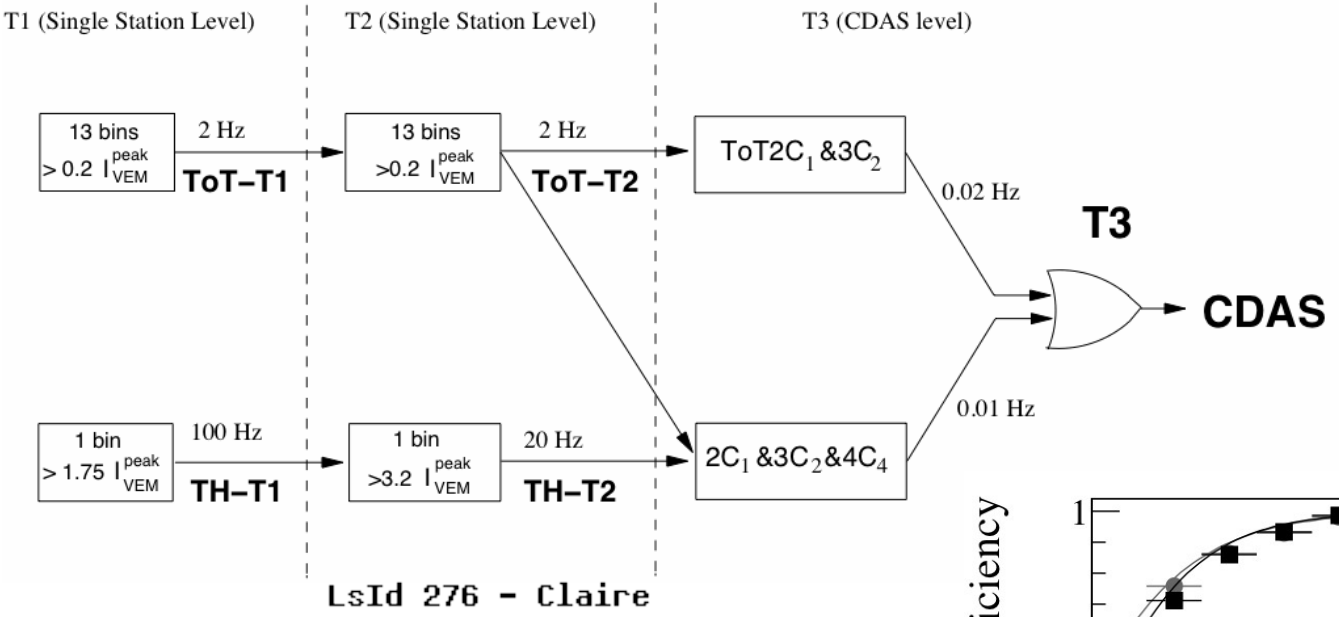
3 – Photomultiplier

Plastic tank filled with 12 tons of water

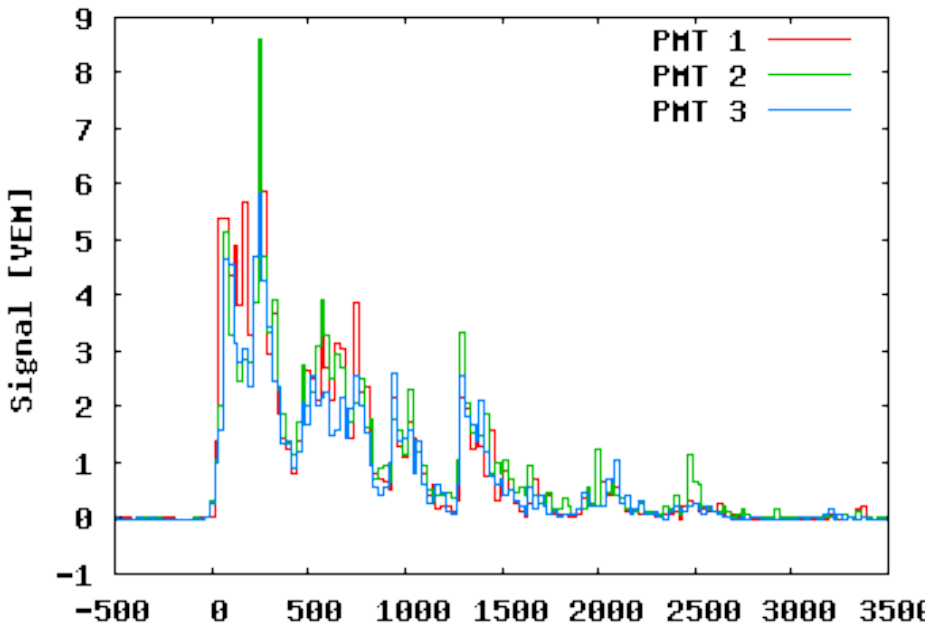
Energy spectrum to the highest energies

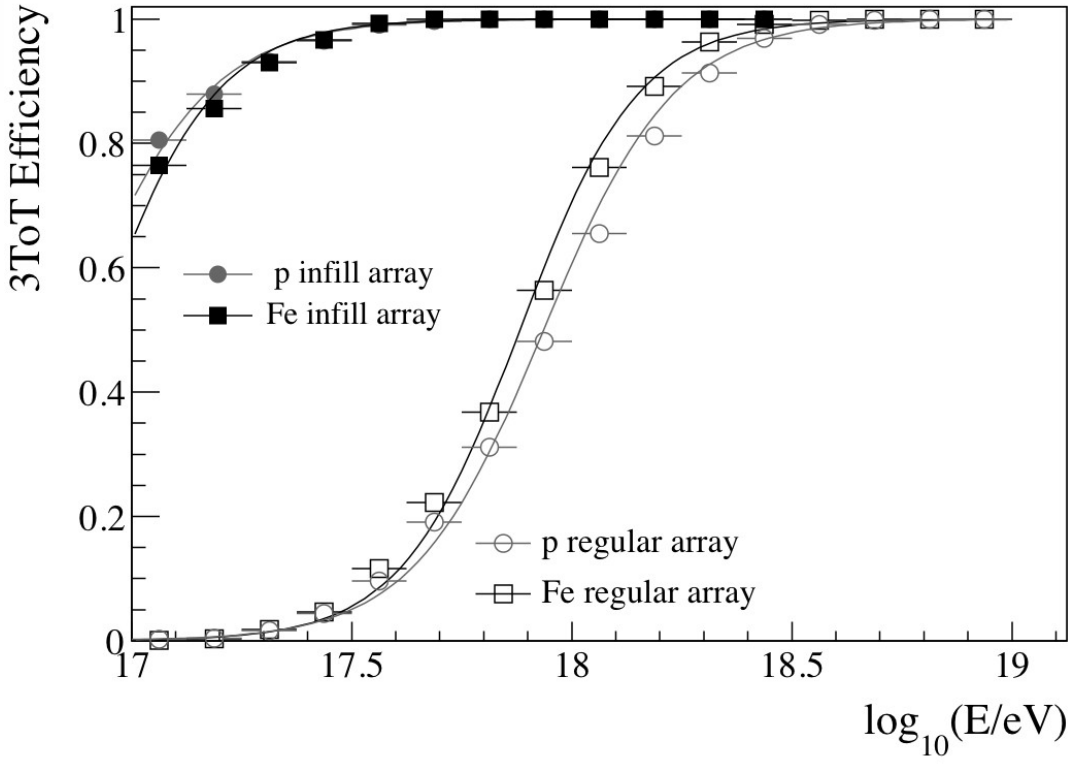


SD Trigger efficiency



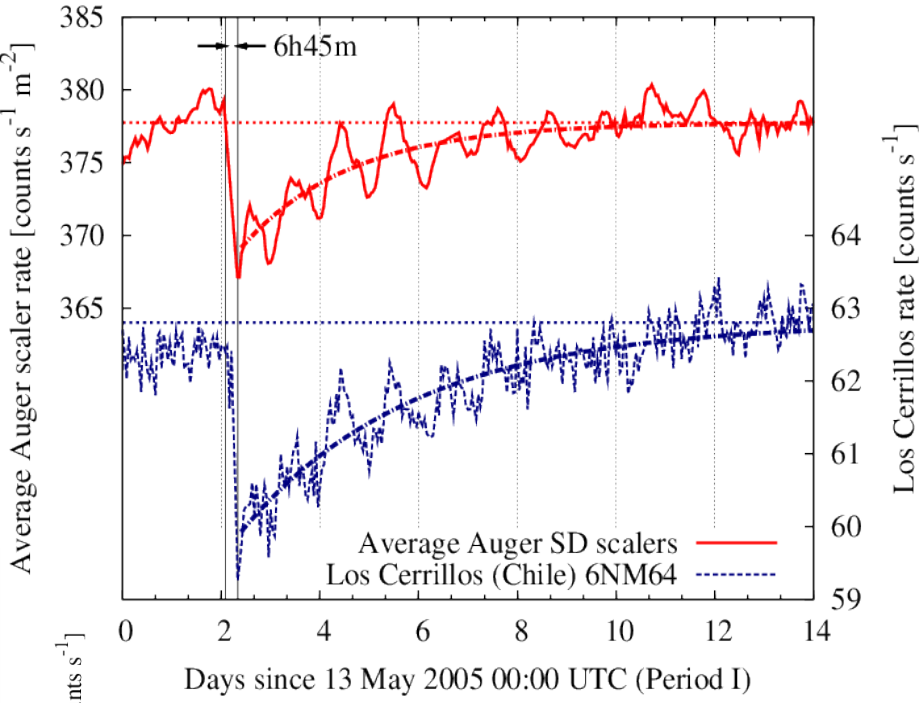
SD-Trace:
40 MHz sampling

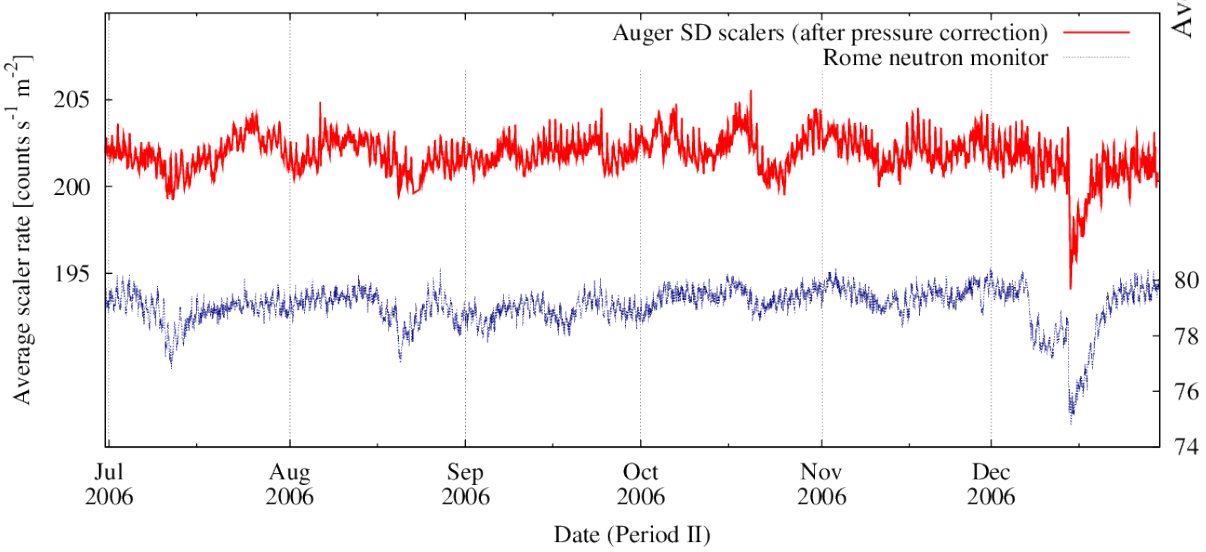




SD-Scaler Measurments

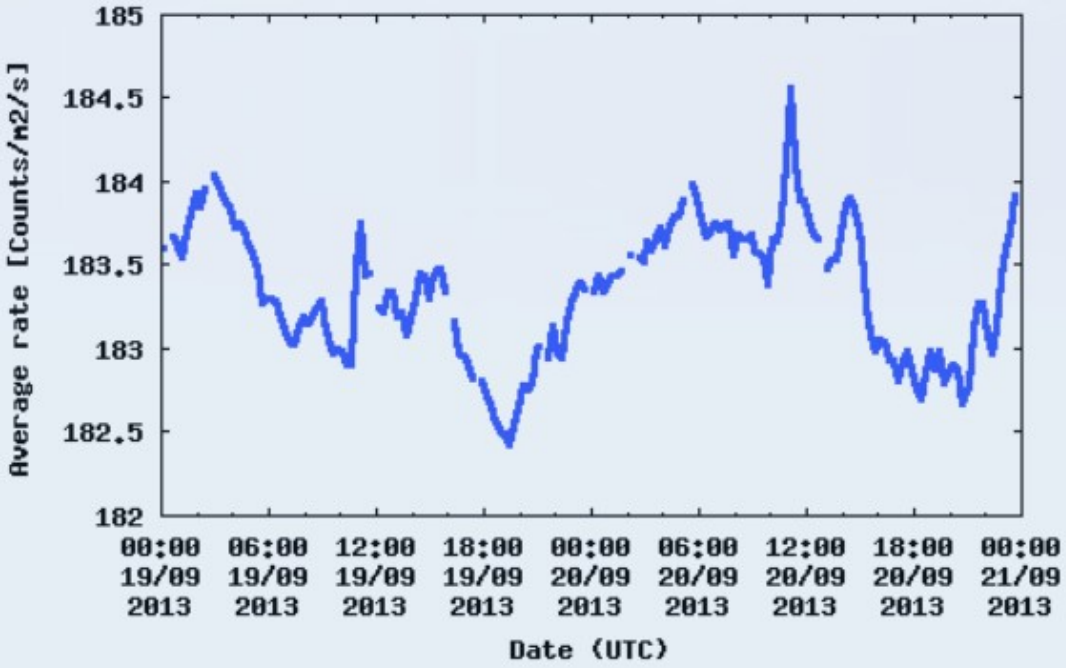
- JINST 6 P01003 (2011)
- Count 12 ns bins with signal above 3 FADC counts (dE/dx ~ 15MeV)
  and upper bound of 20 FADC counts (~ 100MeV) to remove muon background for GRBs searches
- Average ~ 2 kHz
- Good correlation with neutron monitors
- “Space weather”

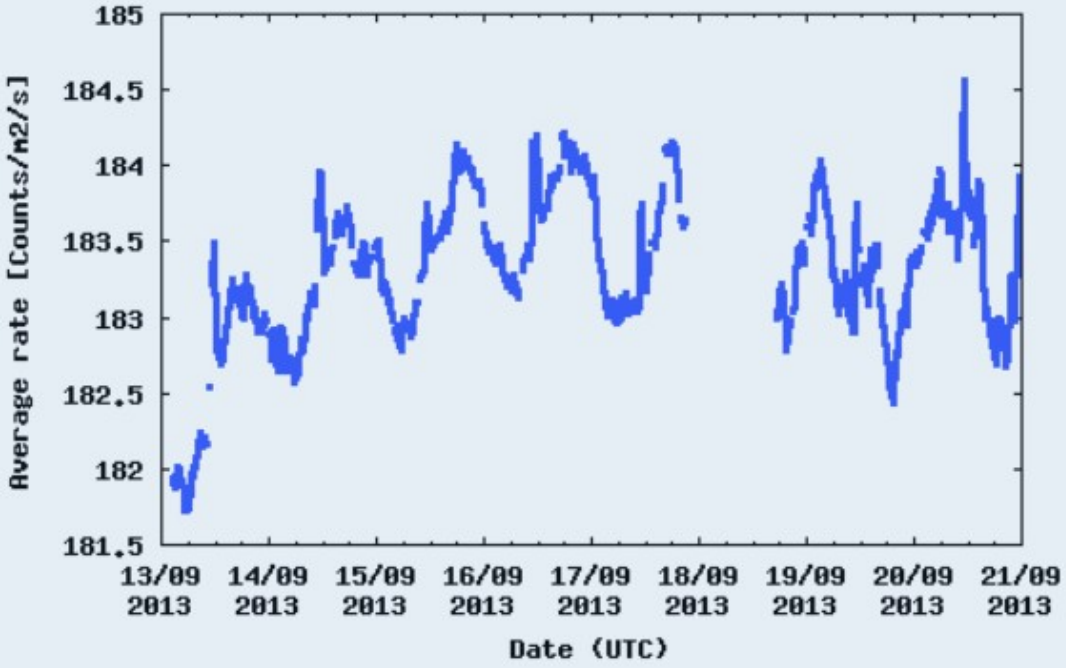




Should you use these data for any publication, acknowledgement to the Pierre Auger Observatory should be given and JINST 6 P01003 (2011) should be cited. You can also download an ascii file with all the dataset.

Latest scaler data





Pierre Auger Observatory
Public Event Explorer

Pierre Auger Observatory
Public Event Explorer

Event Selection

	Min	Max
Nb. of stations	5	
Zenith Angle	0	60
Energy (**EeV**)	15	

Order: Id / Date (reverse)

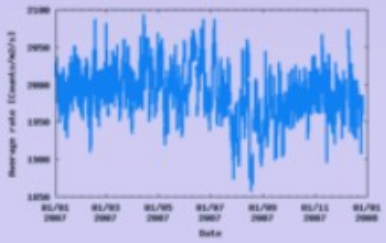
Show 10 Events

Search

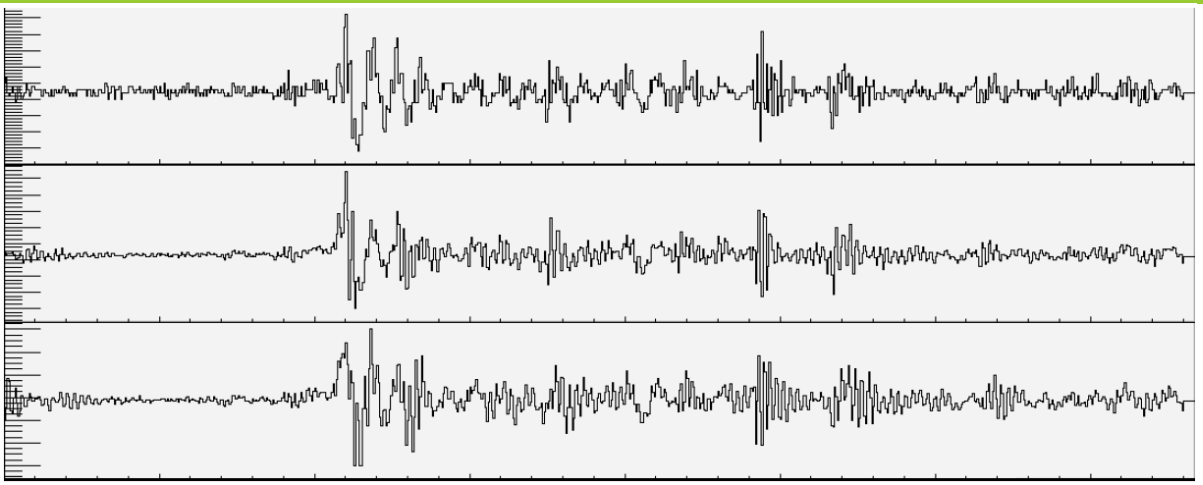
Go to event Id 4128900

Size of the Pierre Auger Observatory

Space Weather page



SD-Scaler Measurments



SD-Trace of a lightning event

Scalers count many “particles”

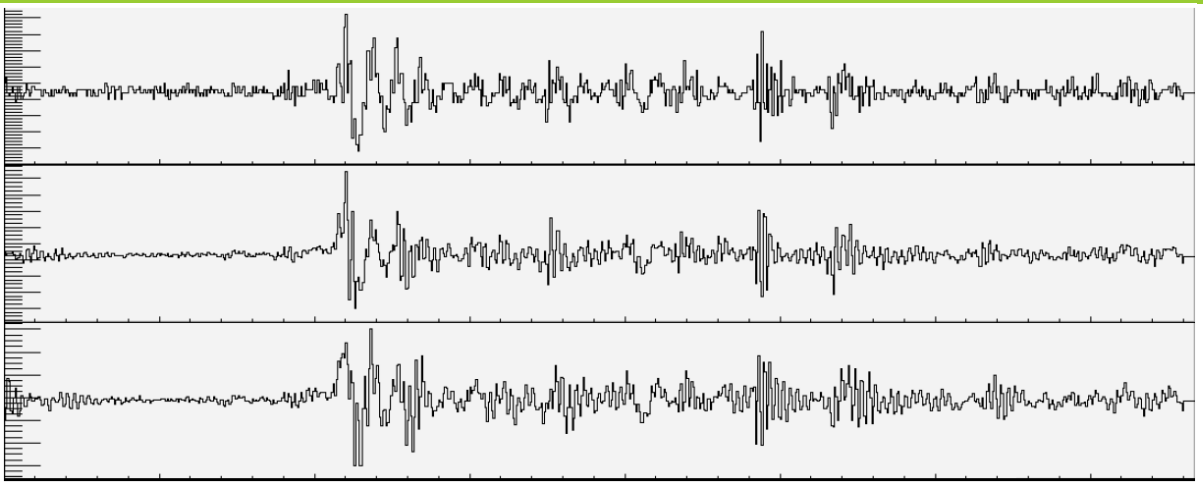
Analysis of Traces give better lightning-indicator

SD-Scaler Measurments

Xavier Bertou

http://www.youtube.com/watch?v=E0h36hPpeJE

SD-Scaler Measurments



SD-Trace of a lightning event

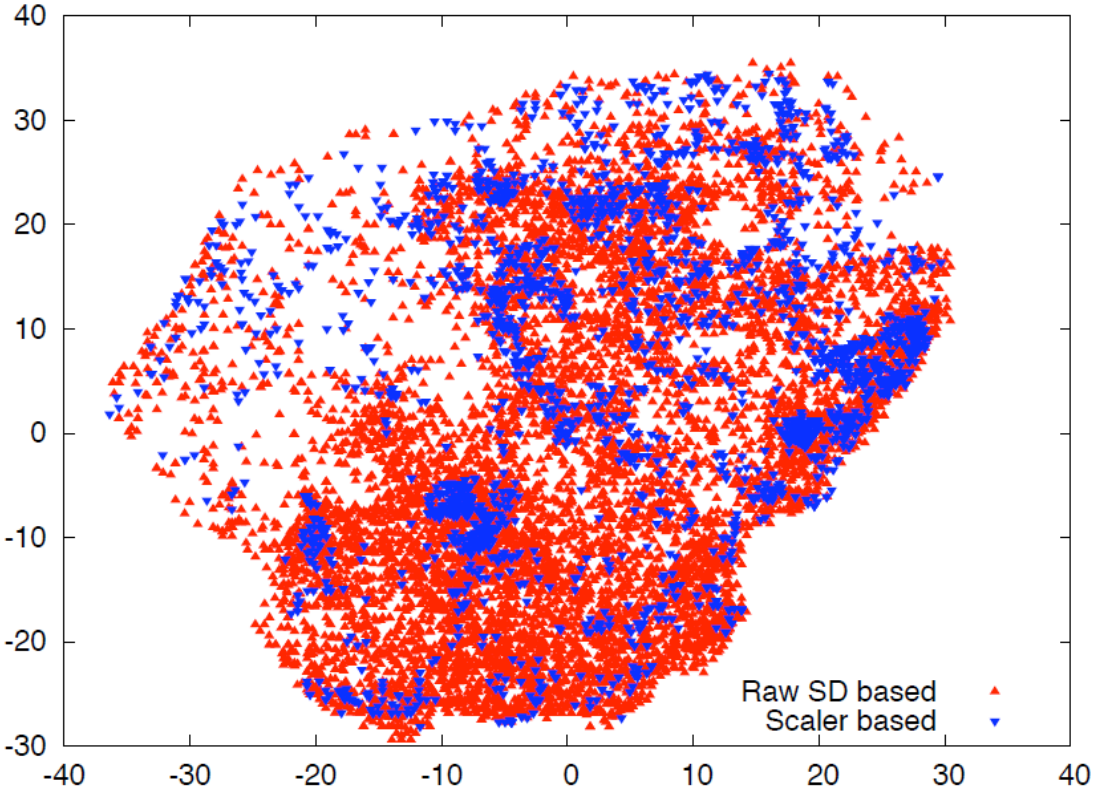
Scalers count many “particles”

Analysis of Traces give better lightning-indicator

Preliminary result:

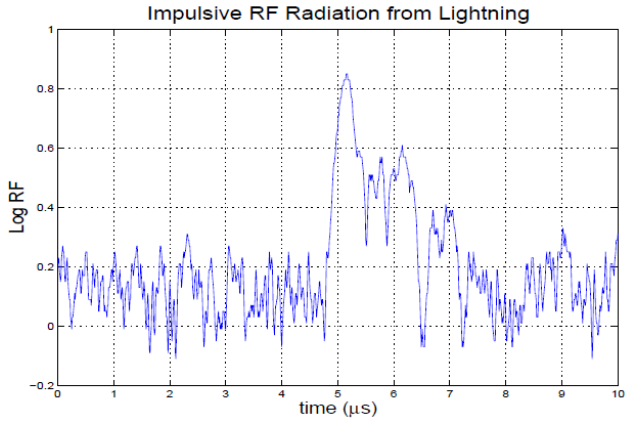
No correlation with Auger-Events due to high energy-threshold log(E/eV)>18.5

Xavier Bertou

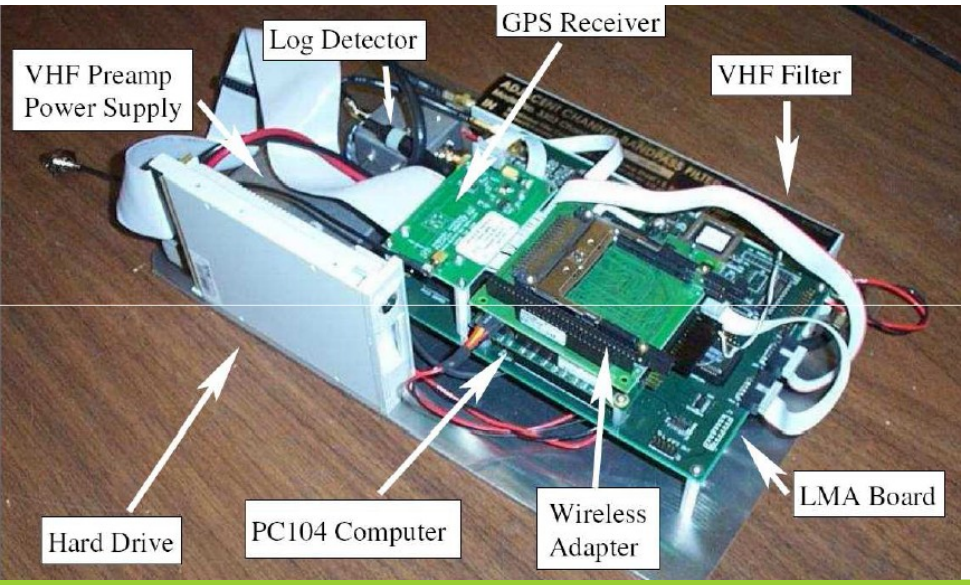


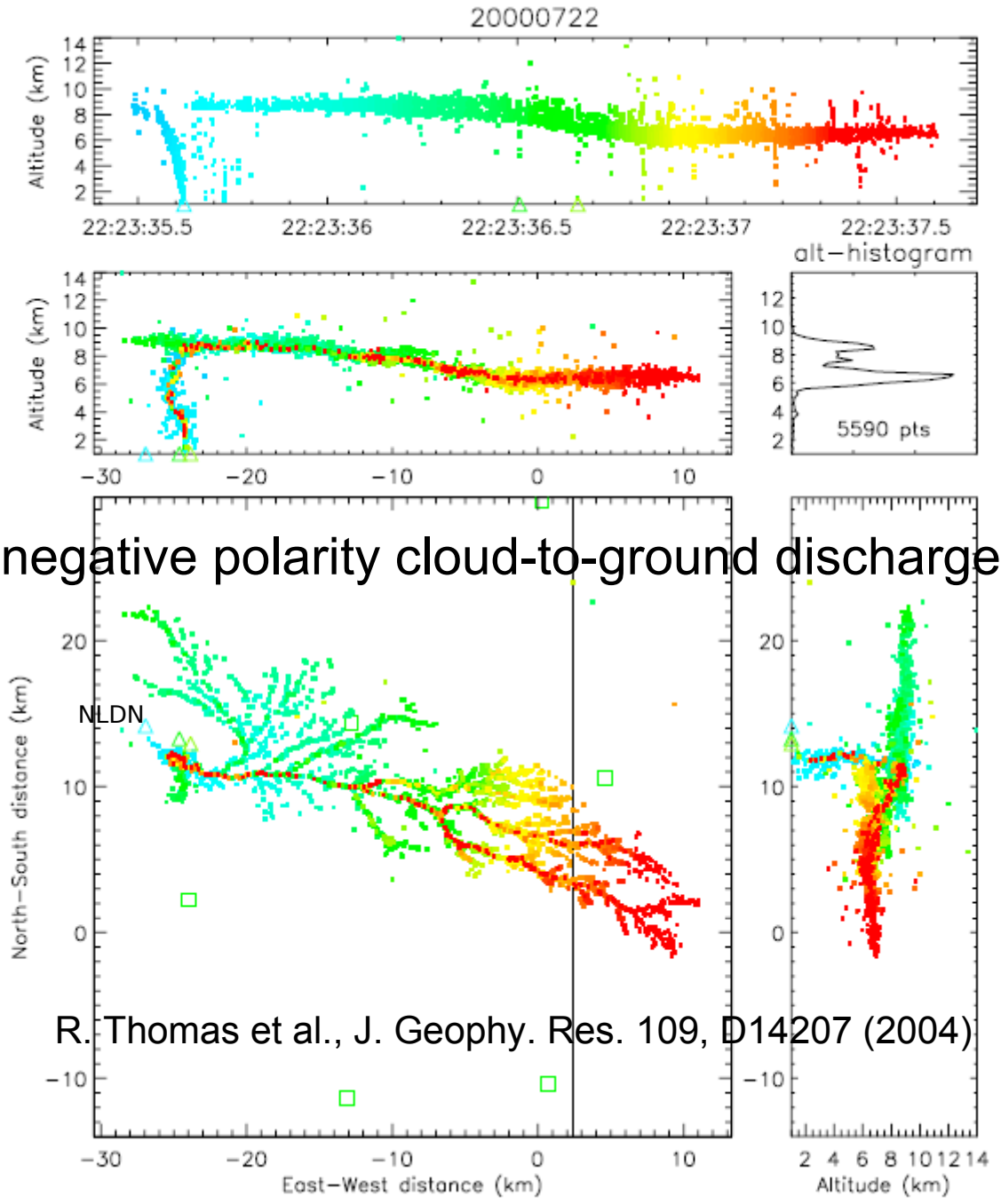
Lightning Detectors

- 60 – 66 MHz observation
- 25 MHz sampling
- Log detector

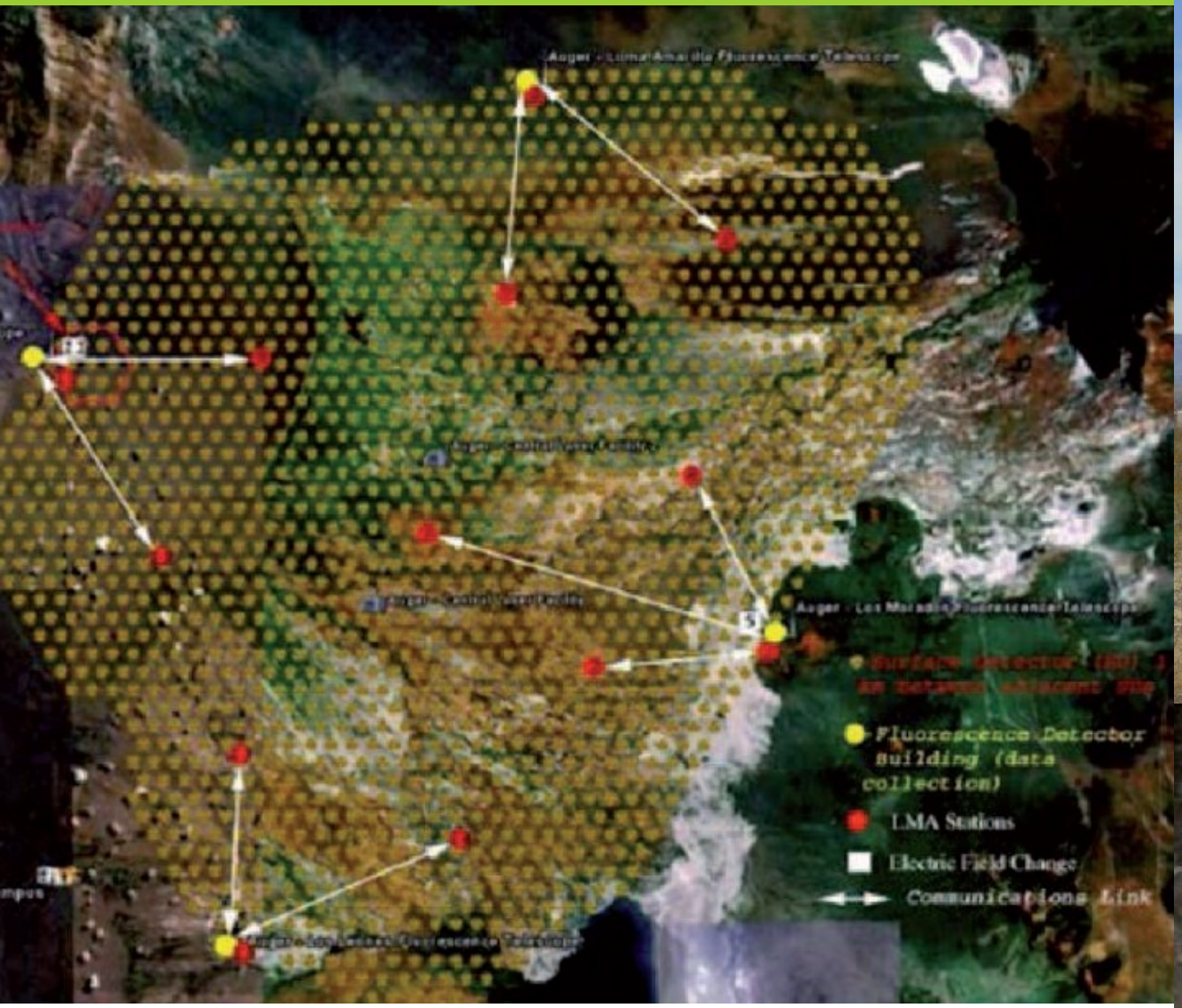


Rison et al., Geophys. Res. Lett., 26 (1999)

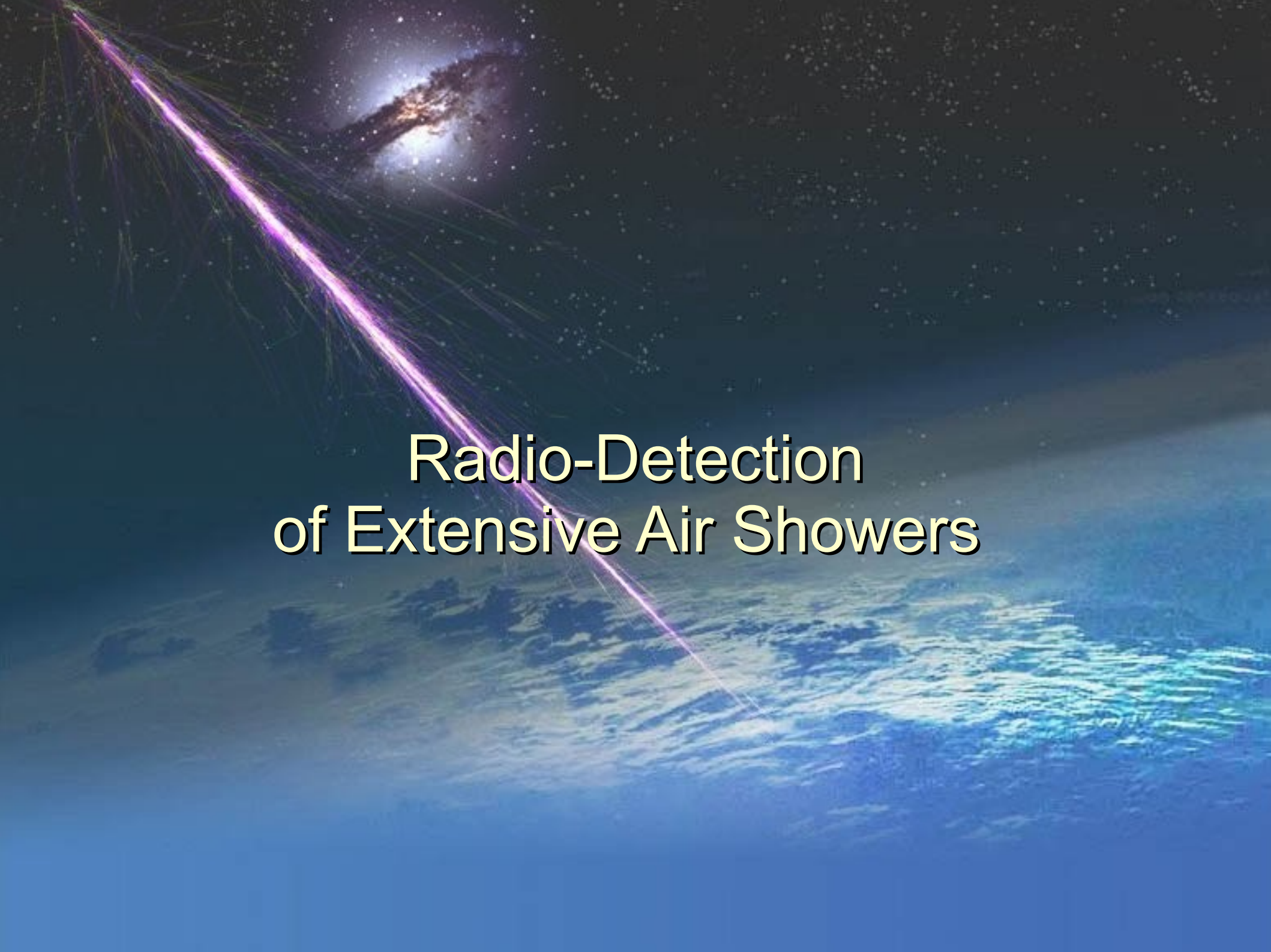




Lightning Mapping Array @ Auger

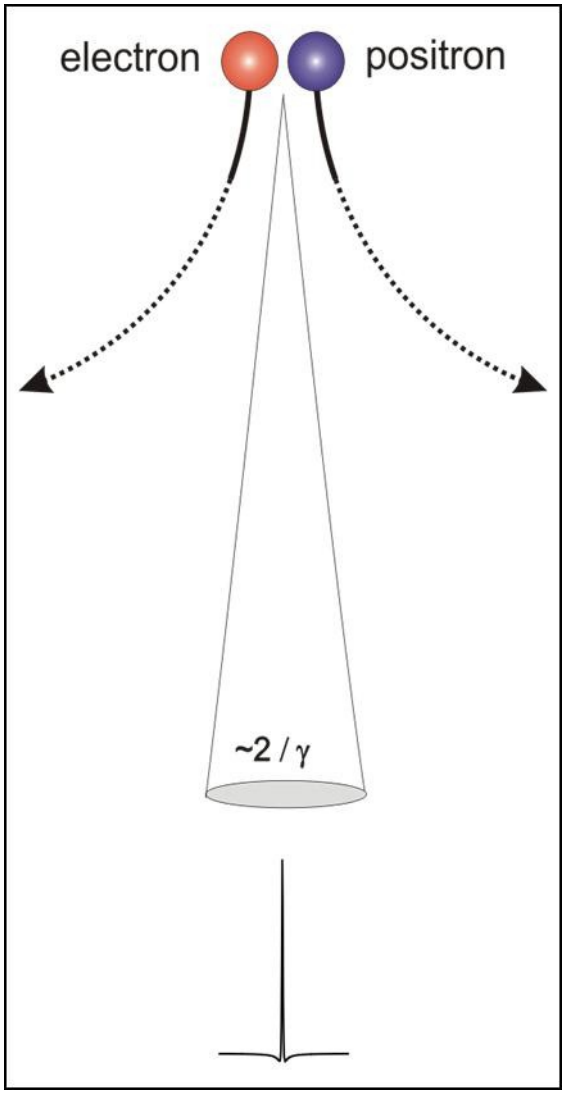


Brown et al., Eur. Phys. J. Plus (2012)


Radio-Detection
of Extensive Air Showers

Renaissance of Radio Detection: Theory

- Early measurements in the 70ties
- Renaissance: Falcke & Gorham A.Ph. (2003)
- Full MC predicting few ns pulses with rather smooth falling frequency dependence and energy scaling
- Geomagnetic effect: v x B
- Coherent emissions from billions of Elektrons
- Emission is focused in beam direction



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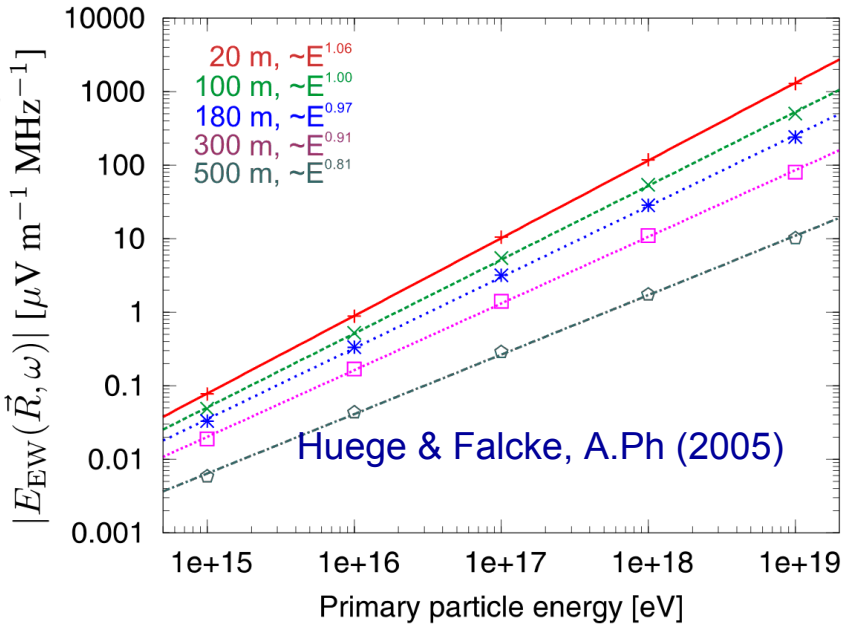
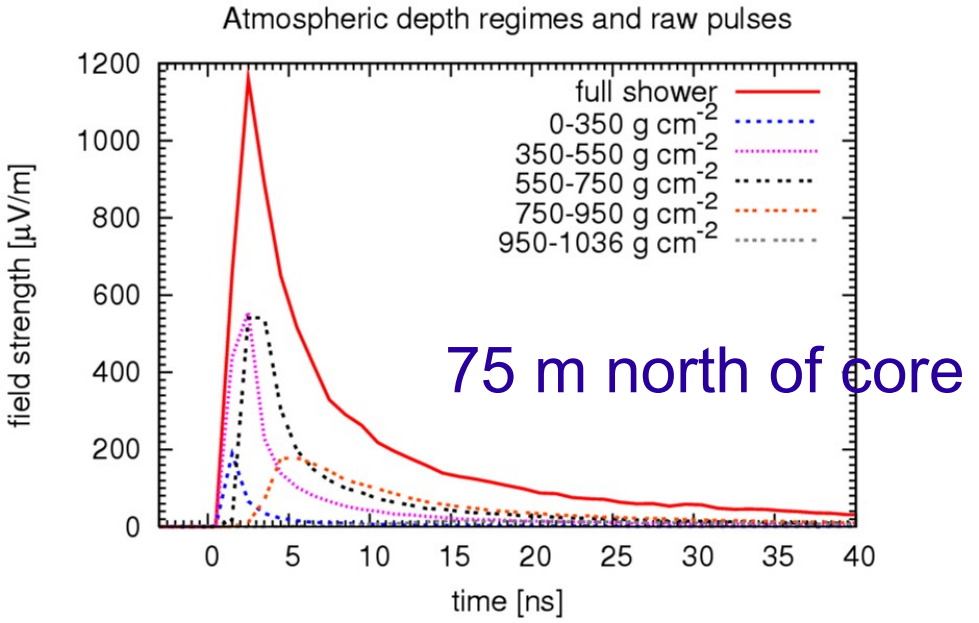
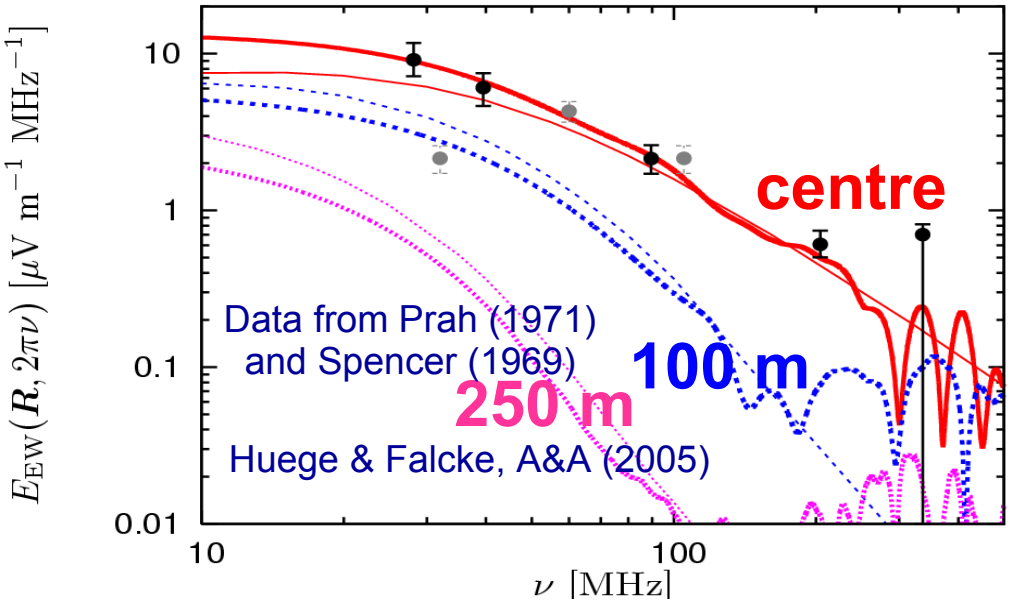






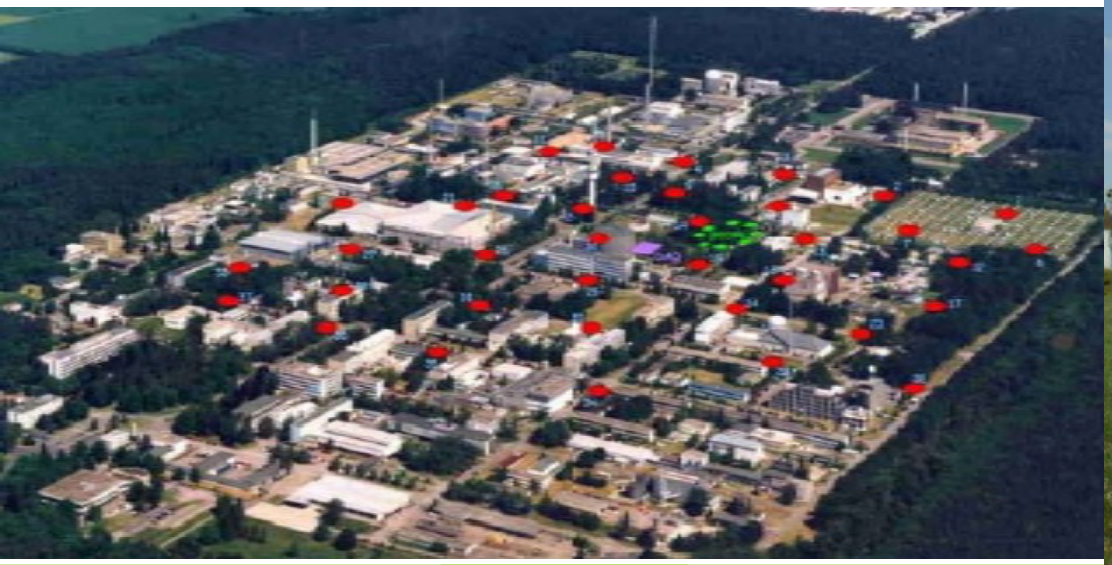
Renaissance of Radio Detection: Experiment

For R&D ideal environment:

- take a running experiment (KASCADE-Grande)
- add new hardware (from new experiment, LOFAR)
- have a look, how EAS look like (Nature 435, 2005)

externally triggered
understand radio-emission
of extended air shower

energy-range from KASCADE-Grande
balance shower-rate and signal-height



Inverted V-shape dipole 40 — 80 MHz
30 channels mainly EW-pol.

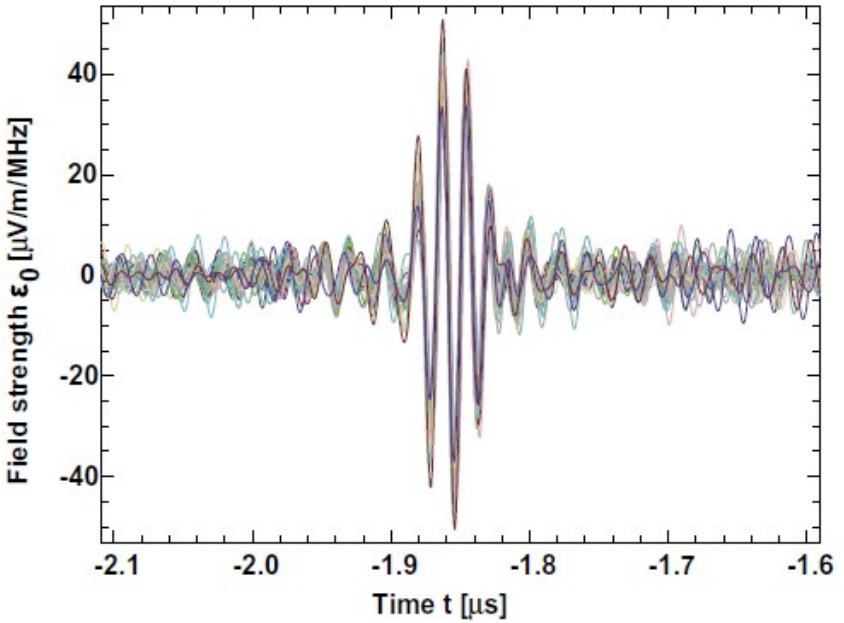
LOPES: Interferometric Reconstruction

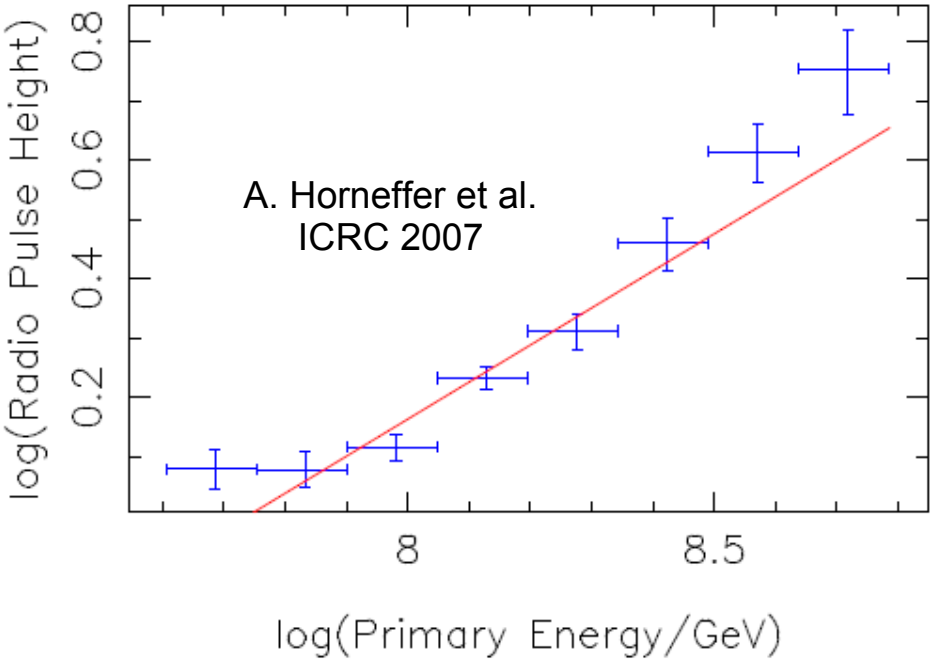
- Cross-correlated beam:

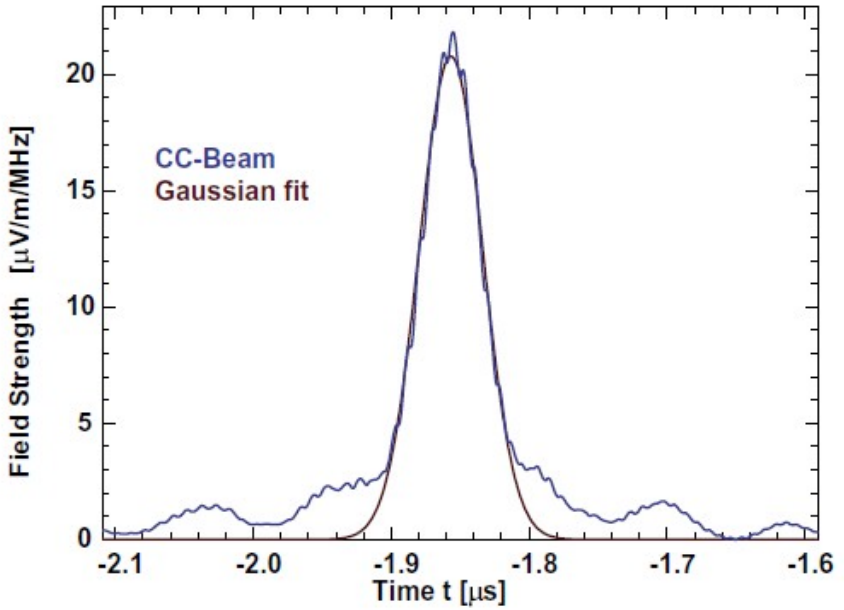
$$cc[t] = \pm\sqrt{\left|\frac{1}{N_{Pairs}}\sum_{i=1}^{N-1}\sum_{j>i}^{N} s_i[t]s_j[t]\right|}$$

$s_i[t]$: signal of station i at time t

- SNR scales with # antenna
- Pulse-hight scales with energy

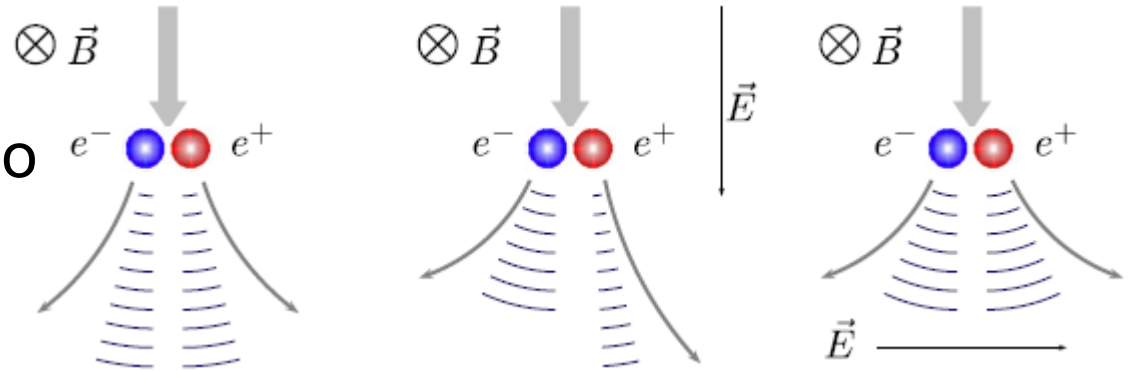




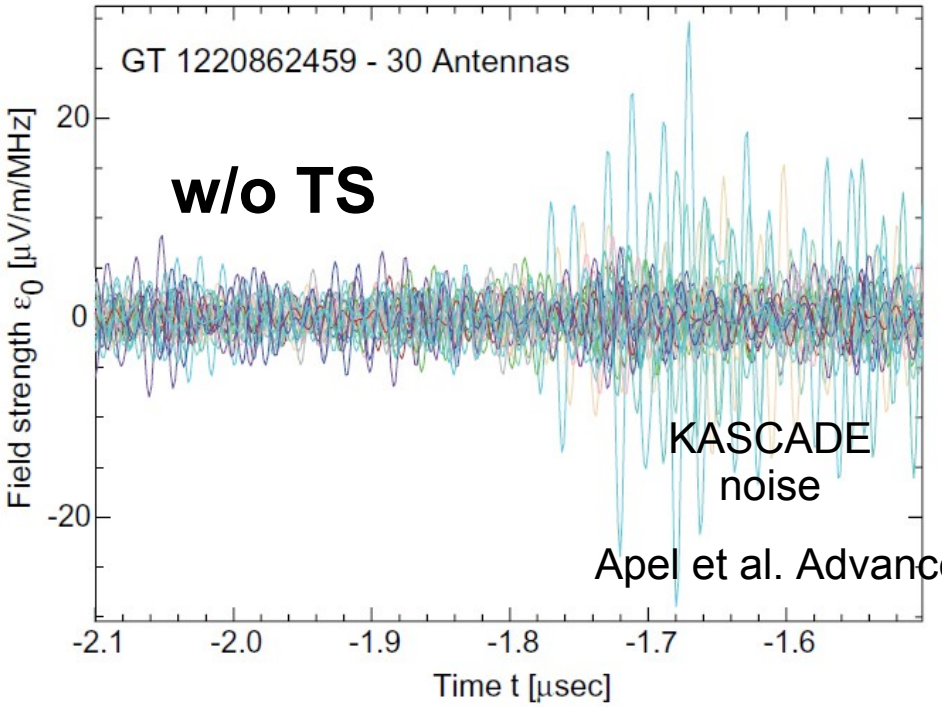


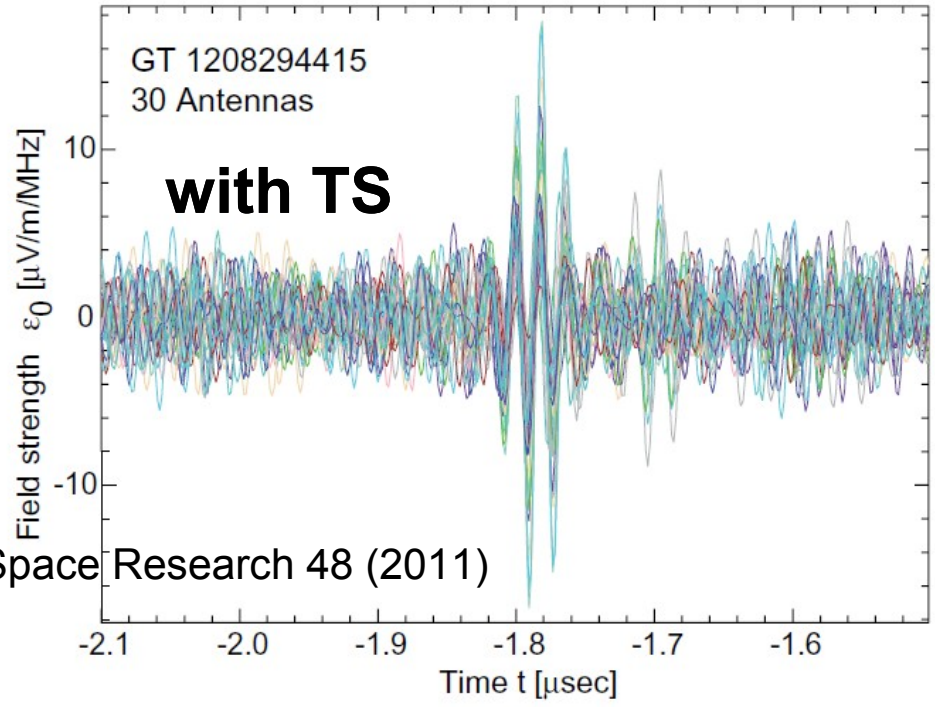
Thunderstorm effect on CR's radio signal

In presence of thunderstorm radio signal can be enhanced by x10



Buitink et al. (LOPES Collaboration) A&A 467 (2007)

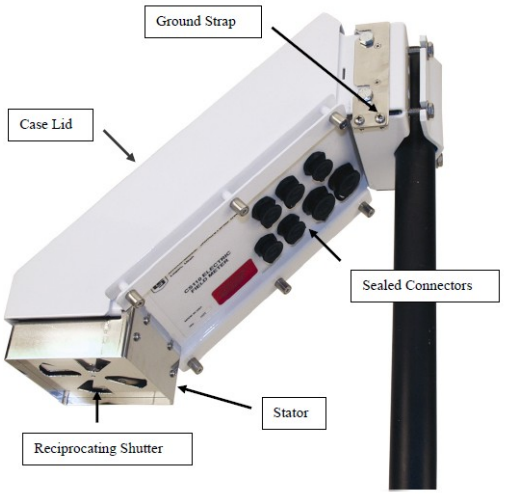


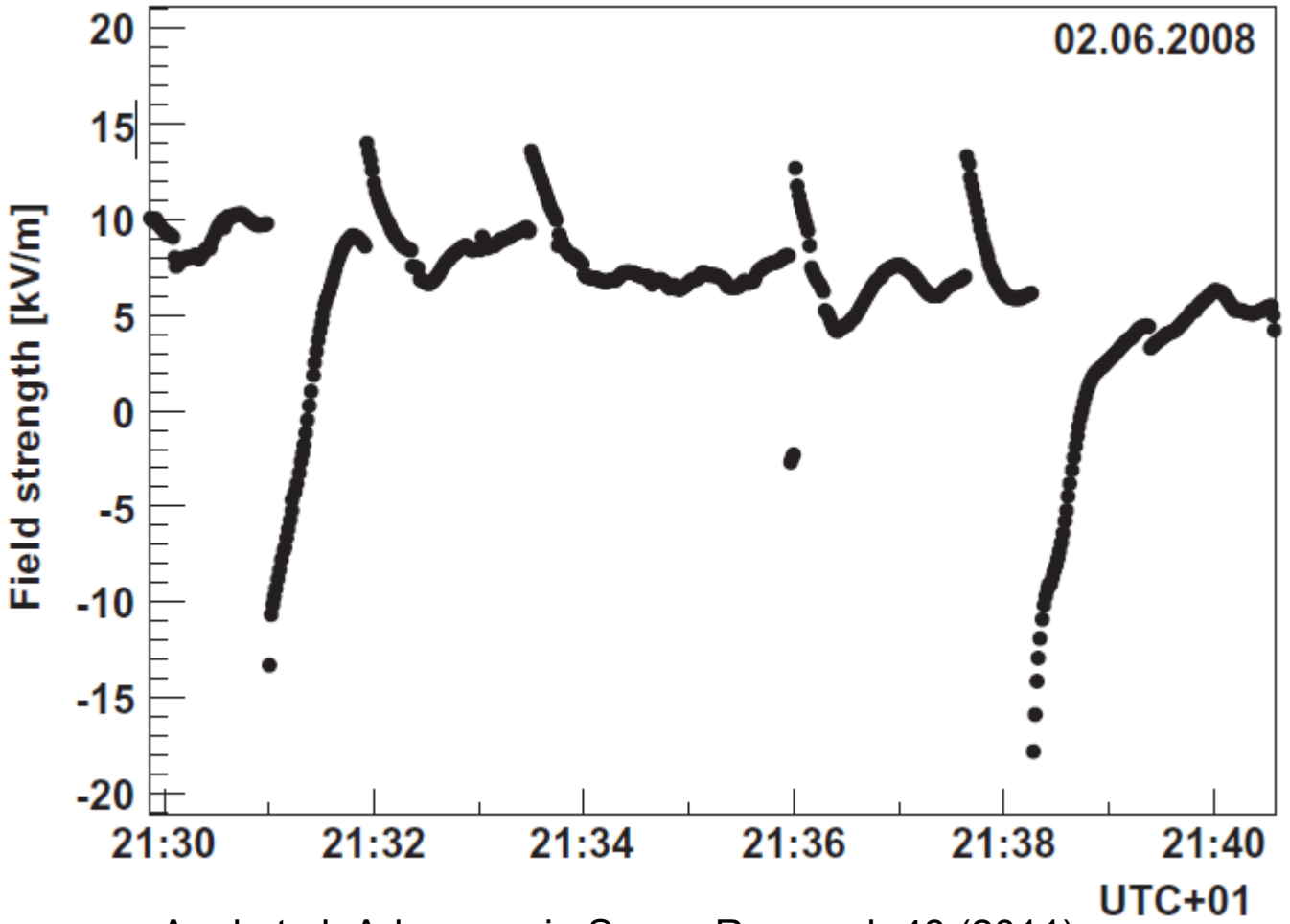


Apel et al. Advances in Space Research 48 (2011)

LOPES E-Fiels mill as Lightning detector

- Strong jumps of kV/m within 1 sec (sampling rate)
- Thunderstorm DAQ-mode reading longer traces

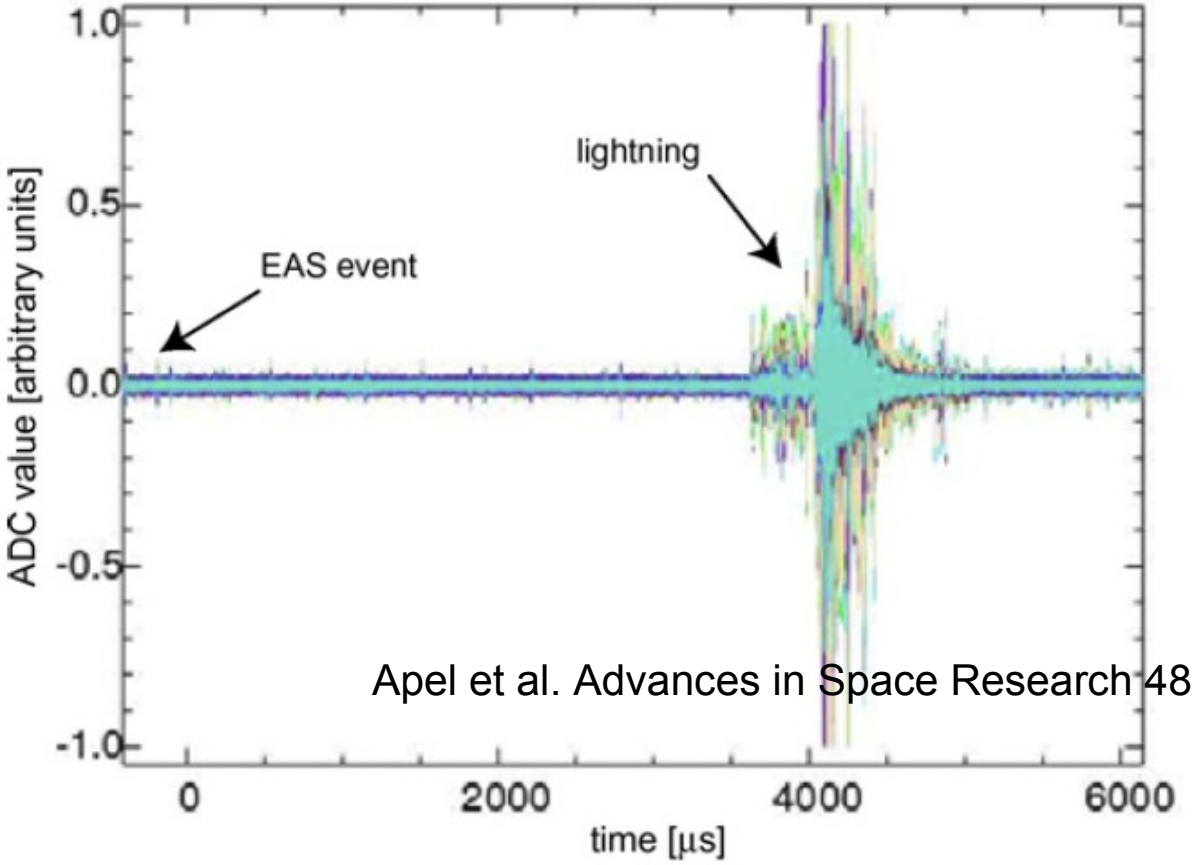




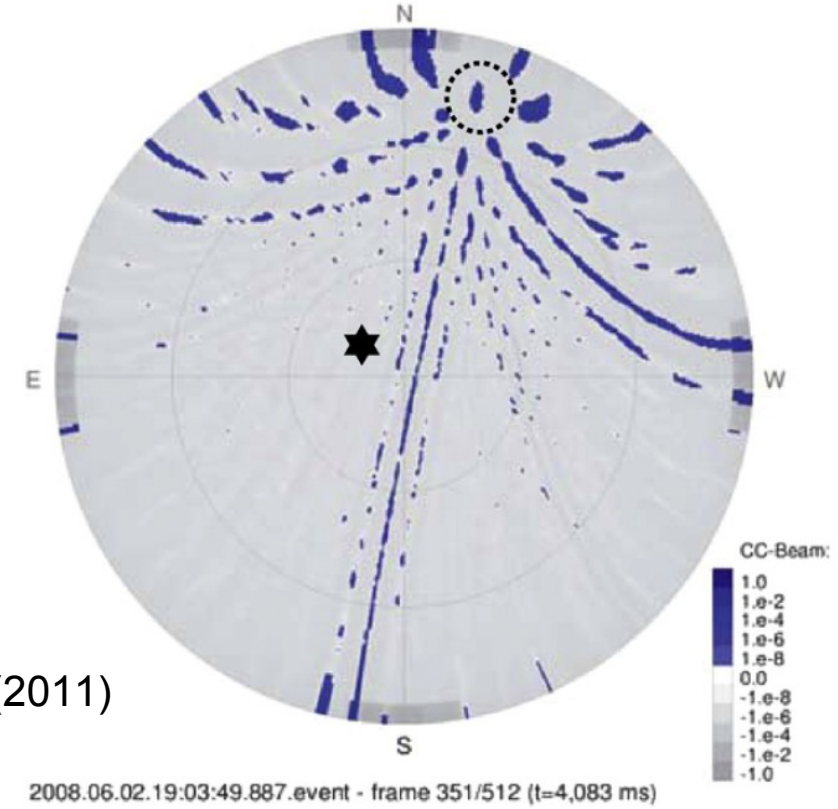
Apel et al. Advances in Space Research 48 (2011)

LOPES Lightning CR correlation

- Analysis of thunderstorm data for correlation
- Signal from relatvistic runaway electron avalance (RREA)? Dwyer, J. Geophys. Res., 115, A00E14, (2009)

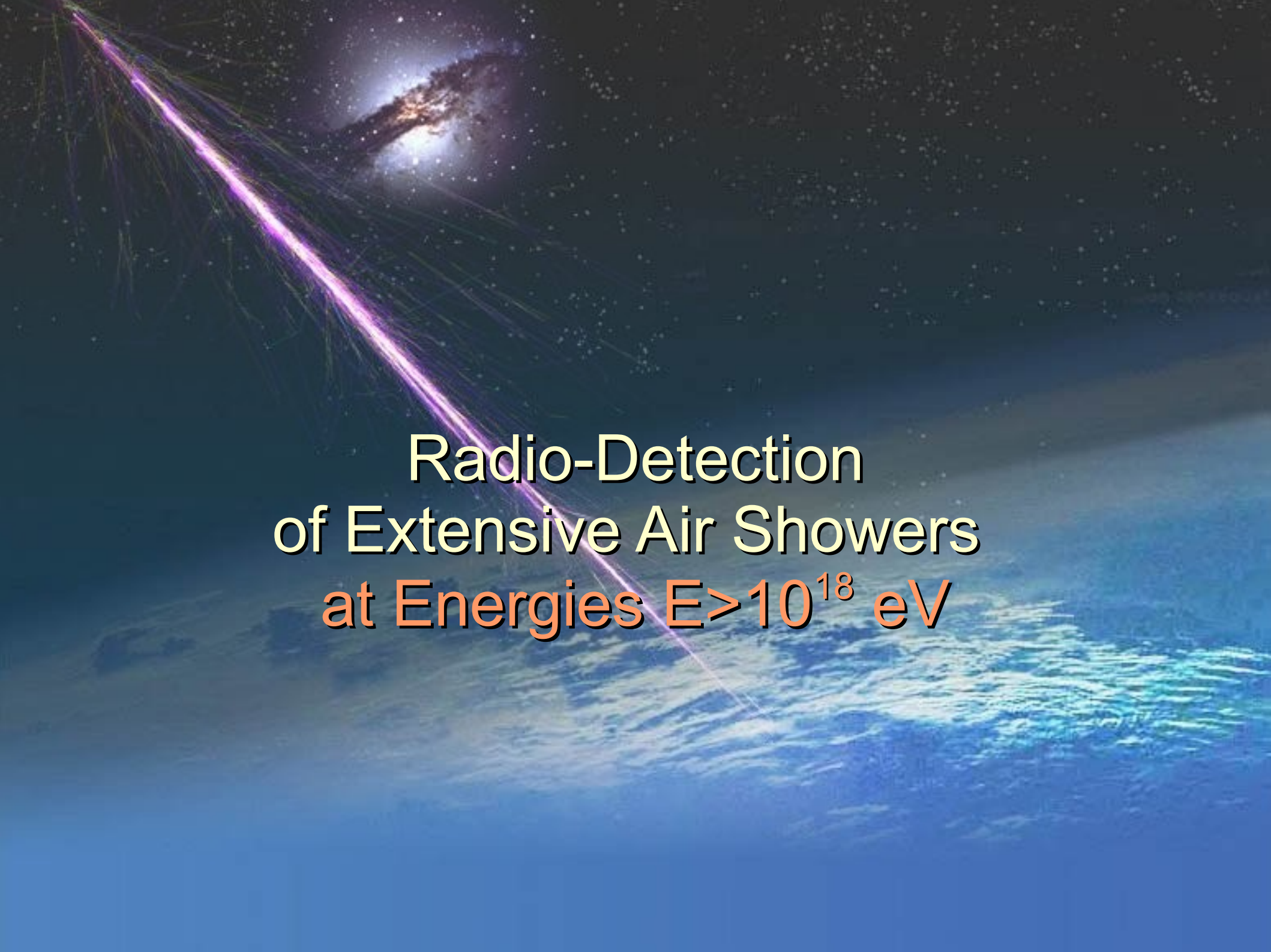


Apel et al. Advances in Space Research 48 (2011)



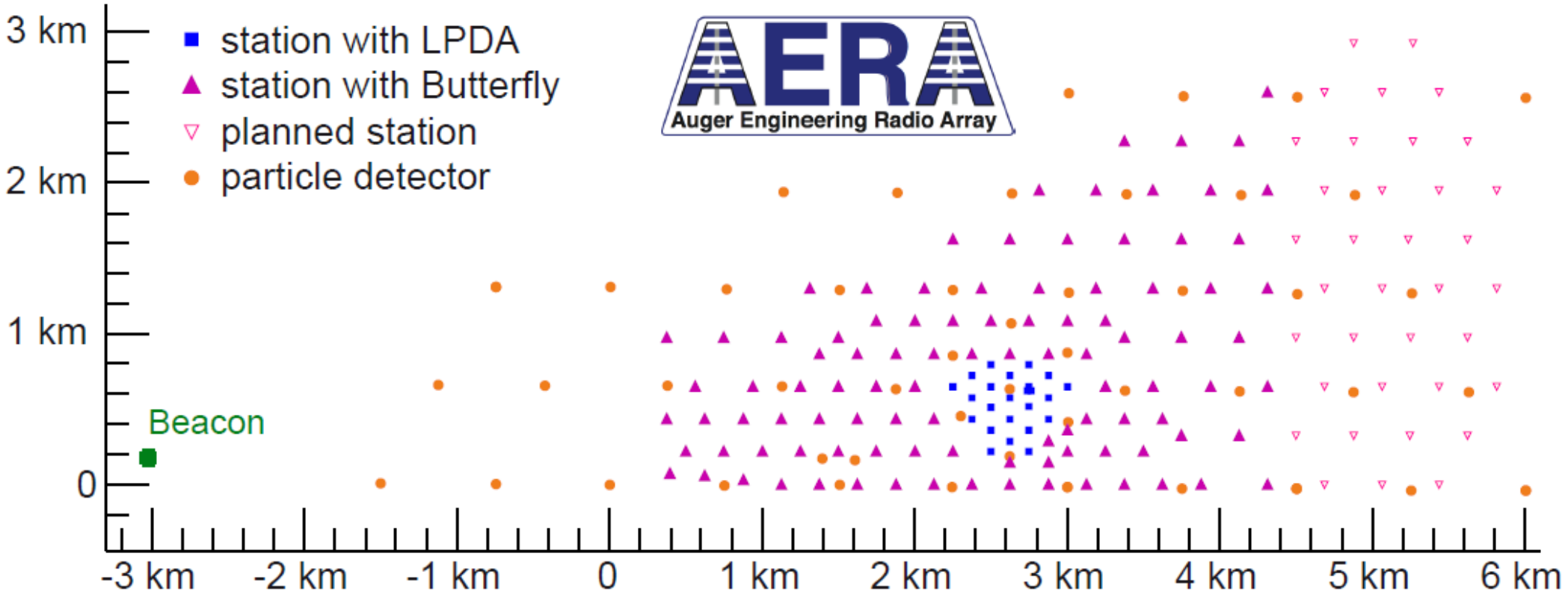
No significant correlation found

Similar RREA-pulse confirmed by Gurevich et al., Phys. Rev. Lett. 110 (2013)

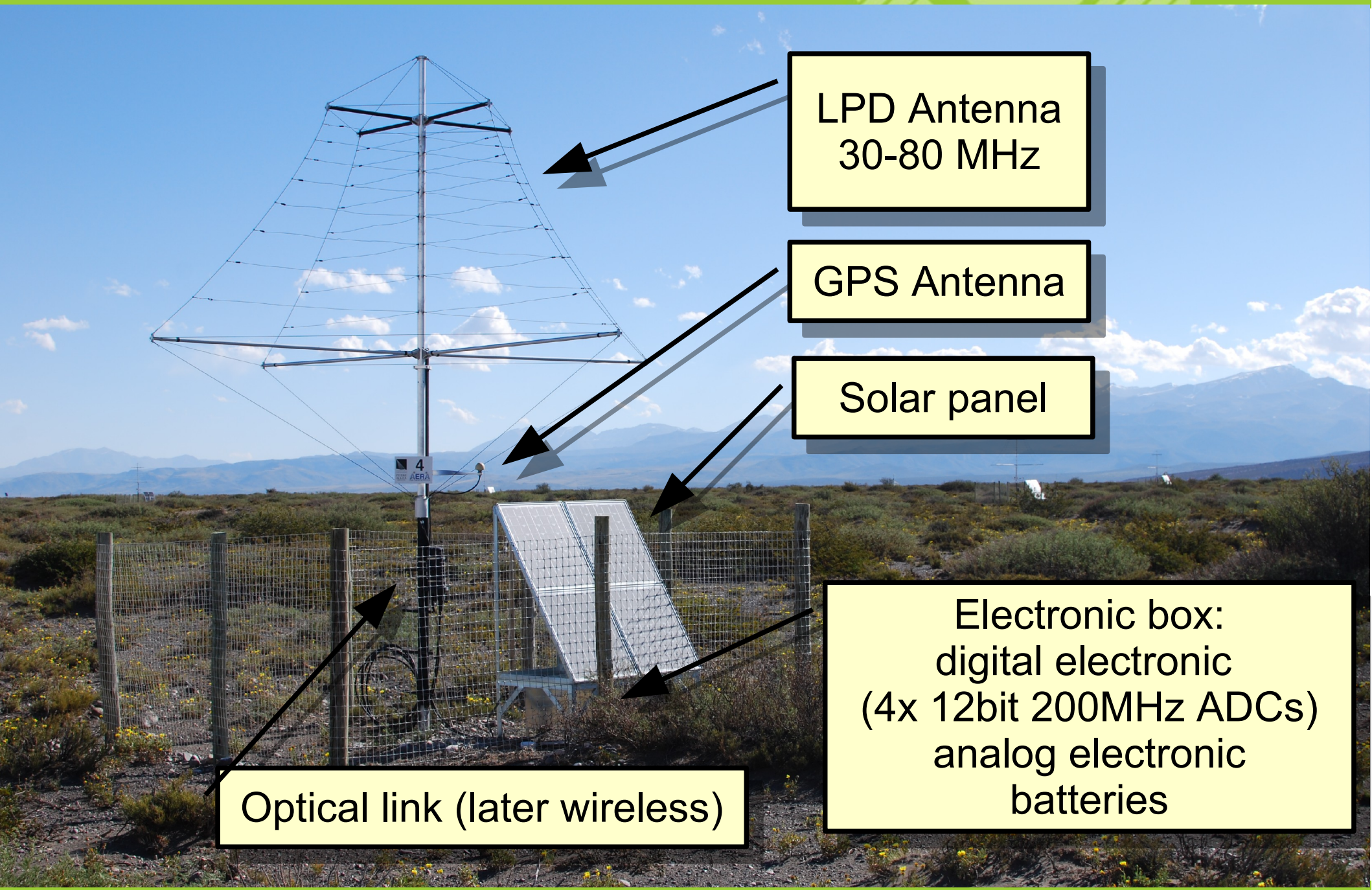

Radio-Detection
of Extensive Air Showers
at Energies E>10^18 eV

Radio EAS detection @ Auger

- 160 radio detector stations on 20 km^2
- Phase II deployed May 2013

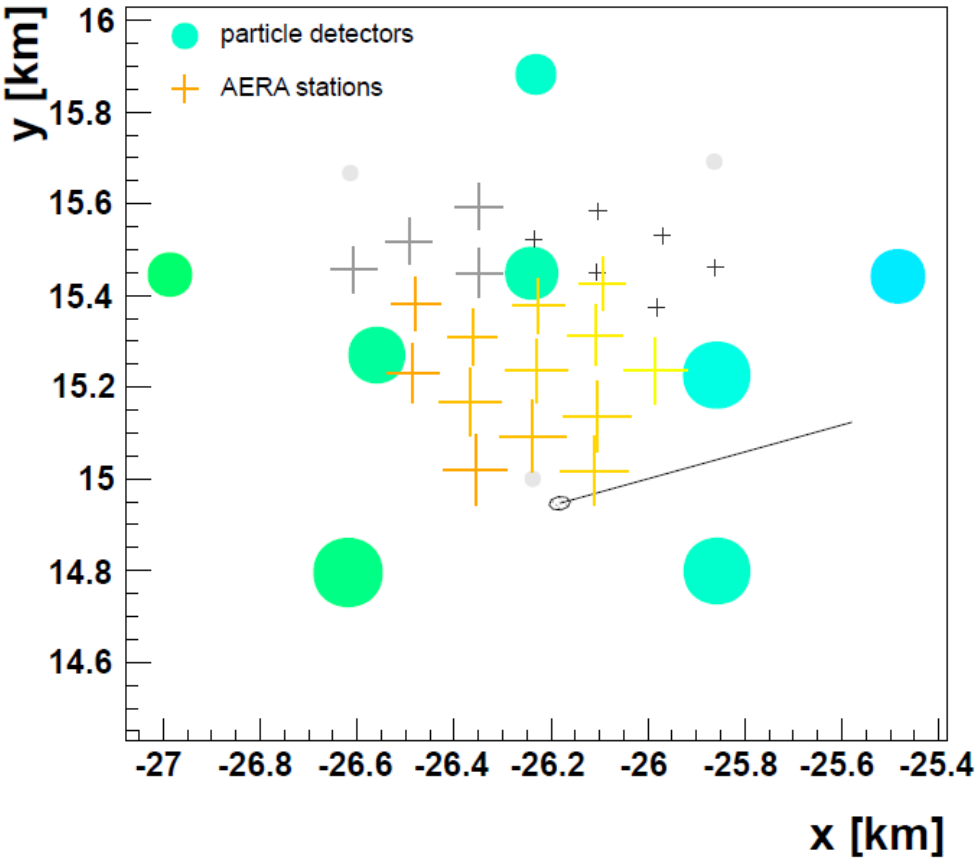


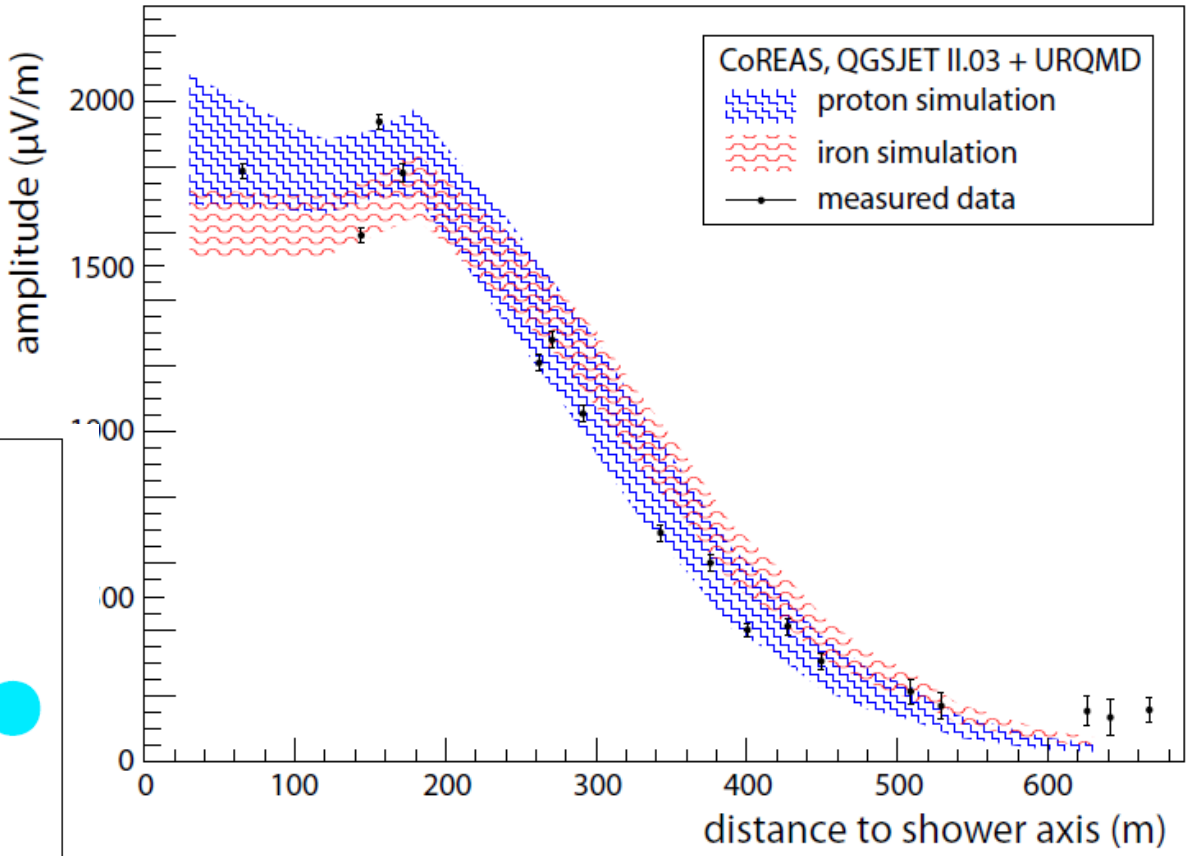
AERA Station



Radio EAS detection @ Auger

- Example event for AERA I
- Well described by simulations

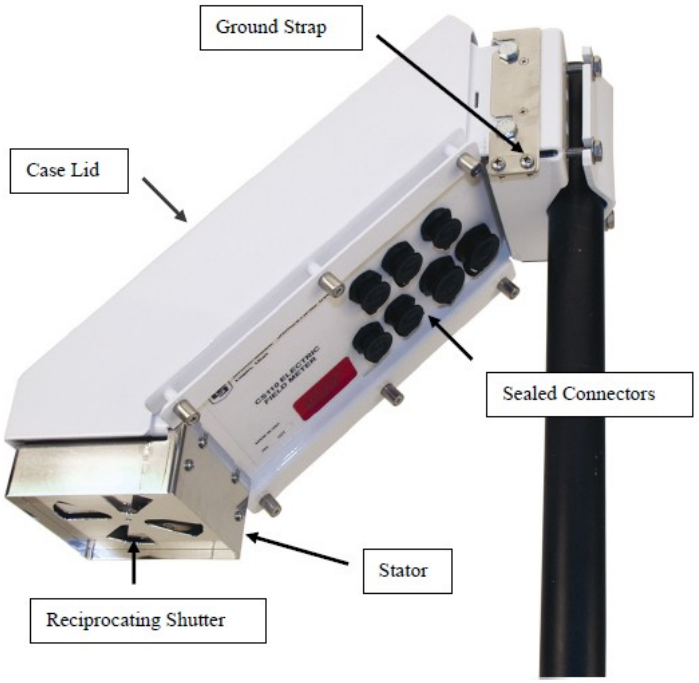


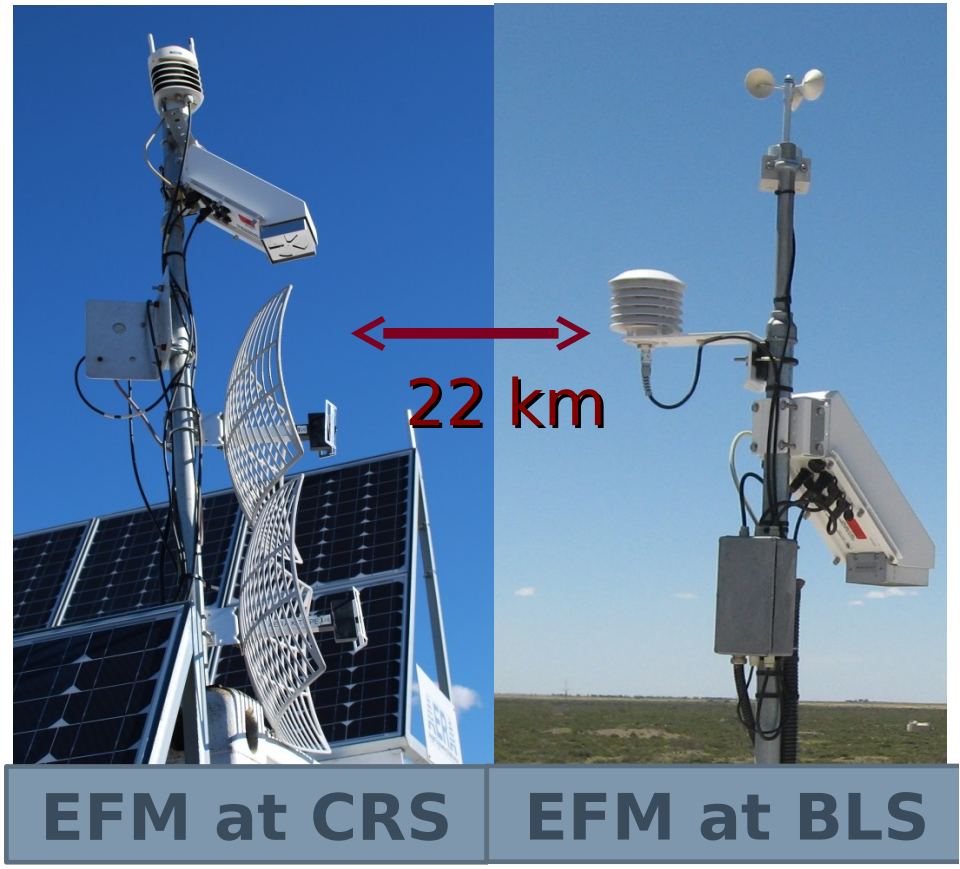


Auger Engineering Radio Array

AERA E-field thunderstorm detection

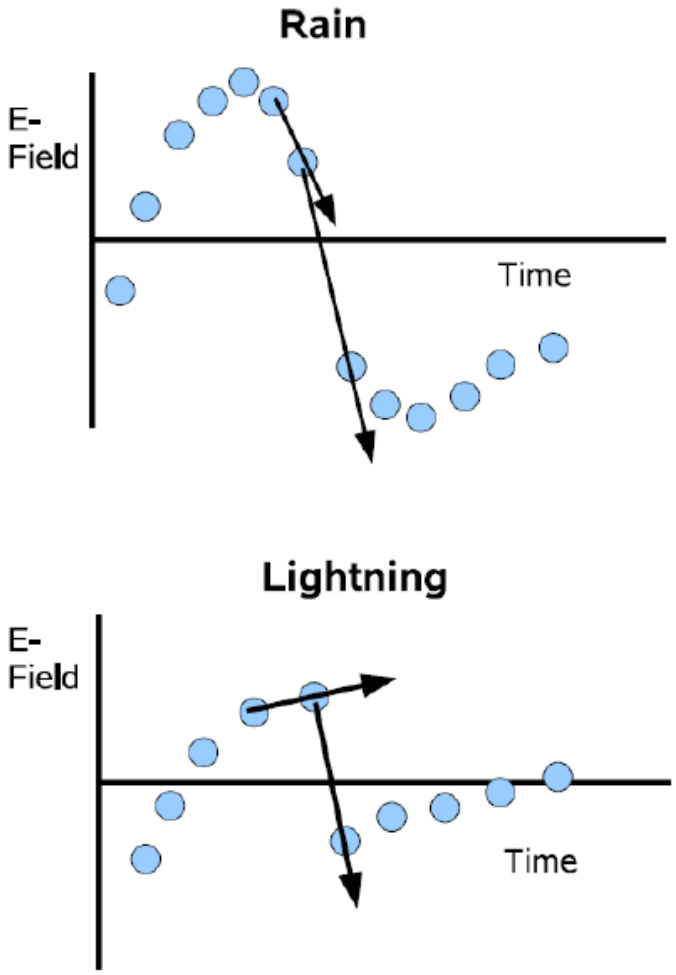
- E-Field mill (Campbell Scientific CS110)
- No spatial resolution
- 1 sec sampling
- 2 stations at Auger





AERA E-field thunderstorm detection

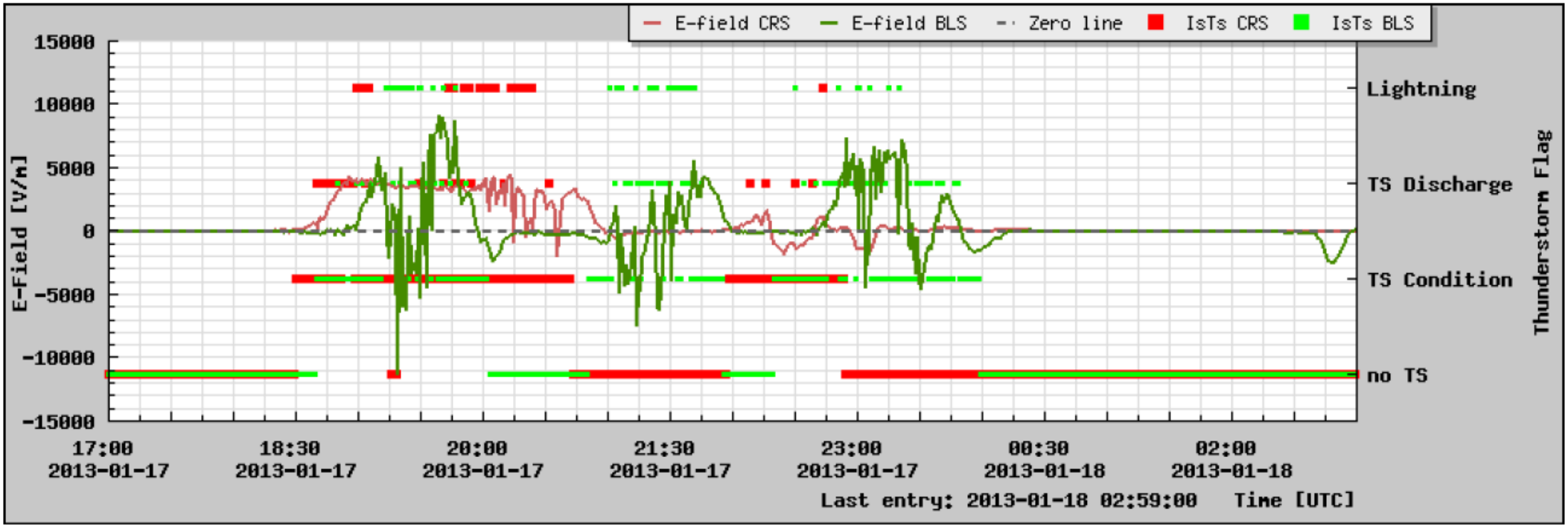
- According to S. Nehls for Lopes
- Requirement:
  - E-Field over Threshold (500 V/m)
  - Jump in data larger then
    $|\Delta_{E-field}| > 2 \cdot RMS_{1\,min}$
    $> E_{jump} = 300\,\mathrm{V/m}$
  - Change in slope larger then 40°
  - Sudden discharge due to lightning
    $(|\Delta_{E-field}| > 15 \cdot RMS_{1\,min})$



- 15 minutes around found event are marked as thunderstorm

AERA E-field thunderstorm detection

- Available in Auger Monitoring
- Already at 25 km differences in detection on ground

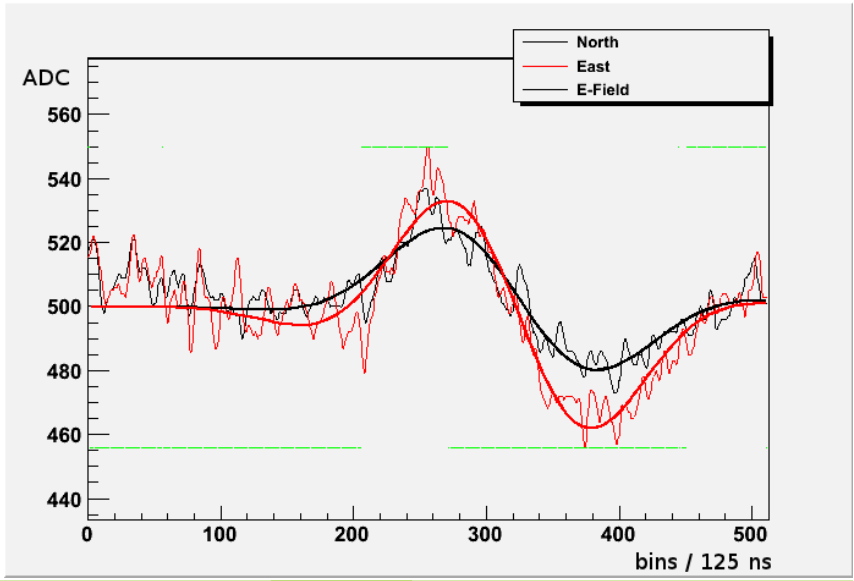


Lightning detection for AERA

Boltek StormTracker:

- Sensitive in kHz-region
- Semiprofessional system
- Lightning detection up to 500 km
- Roughly estimation of direction via fraction of N/S and E/W polarization
- Three systems installed in November 2012 in Argentina
- Time accuracy of PC

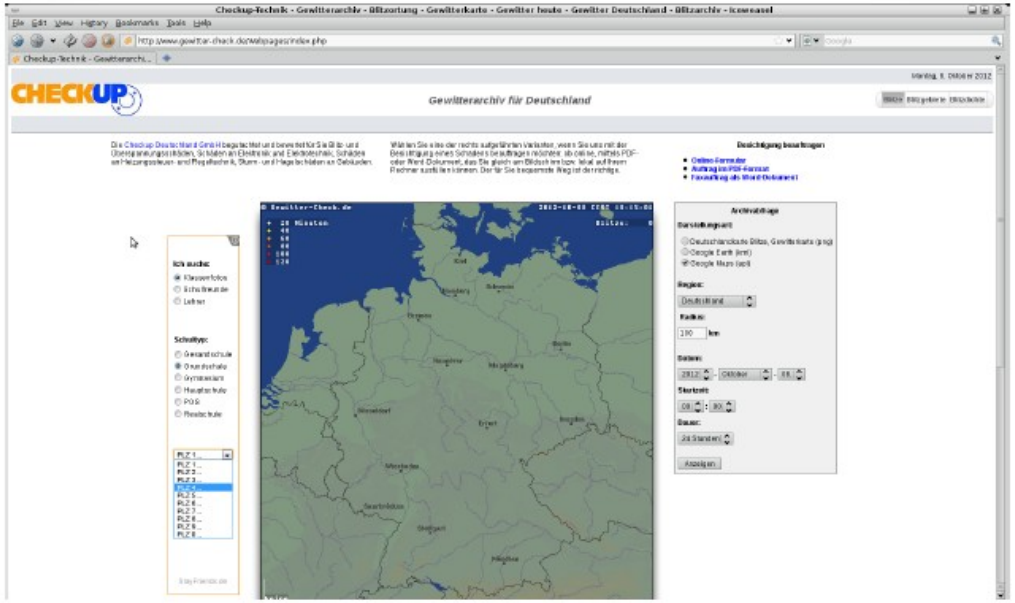
Uncertainty of order 10 ms
not enough for triggering
other detectors

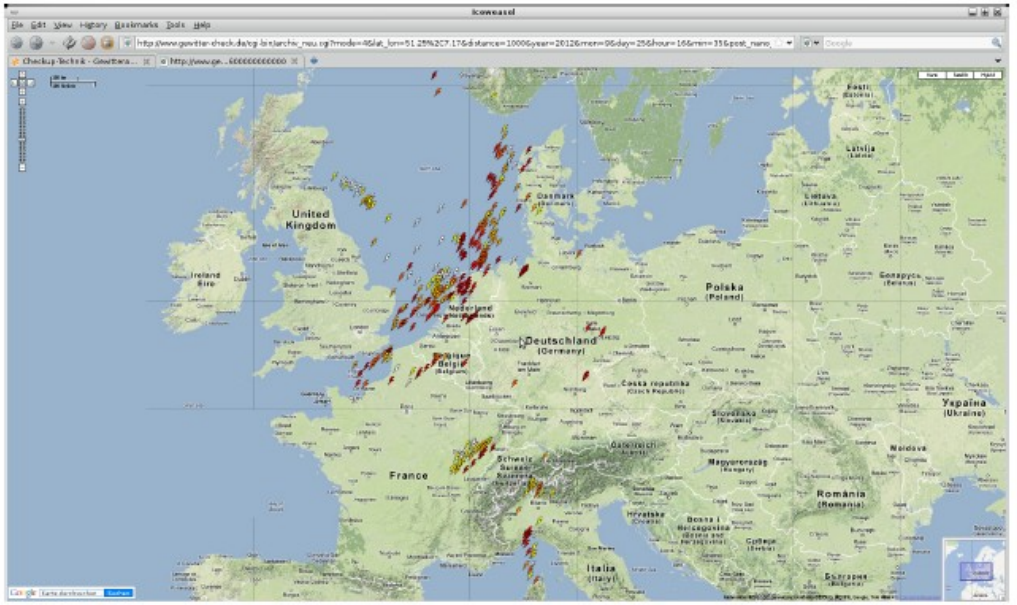


Lightning detection for AERA

CheckUp System (www.checkup-technik.de)

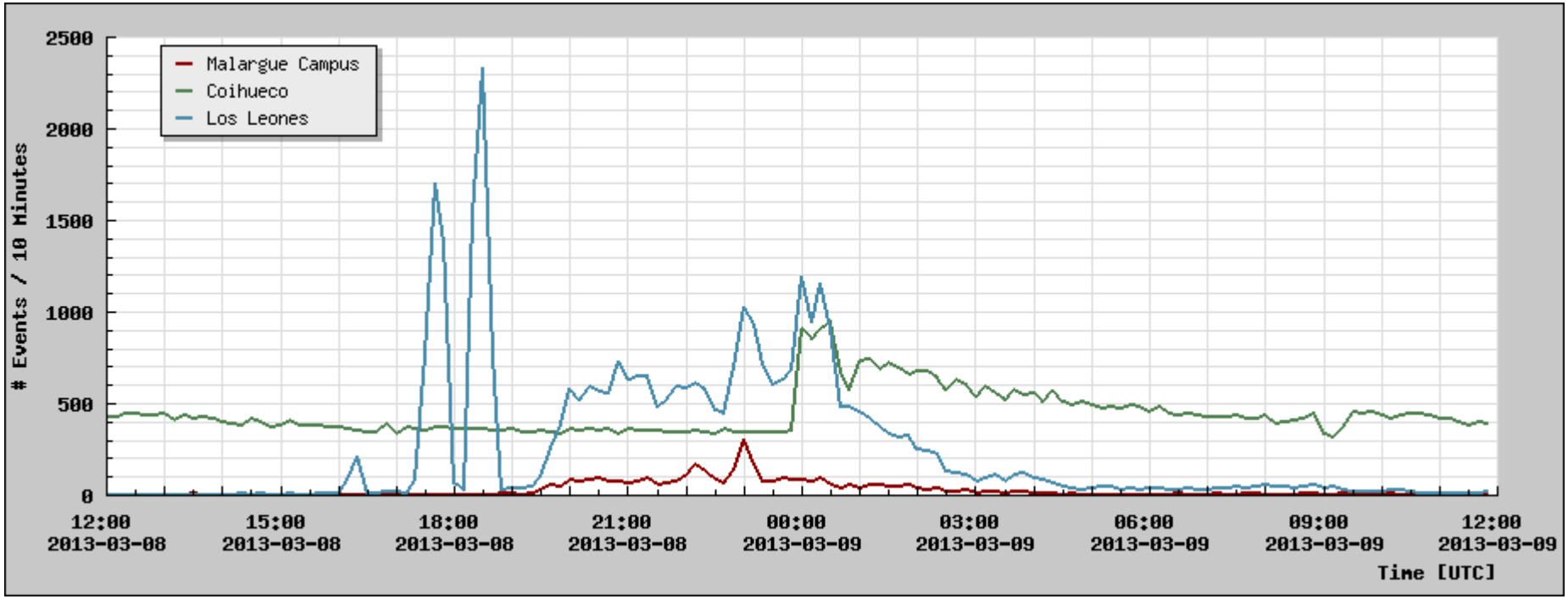
- 13 Boltek StormTracker with GPS-module in Germany
- Time of Arrival - Reconstruction
- ca. 100 m spacial resolution
- Webinterface delivers Google Earth data





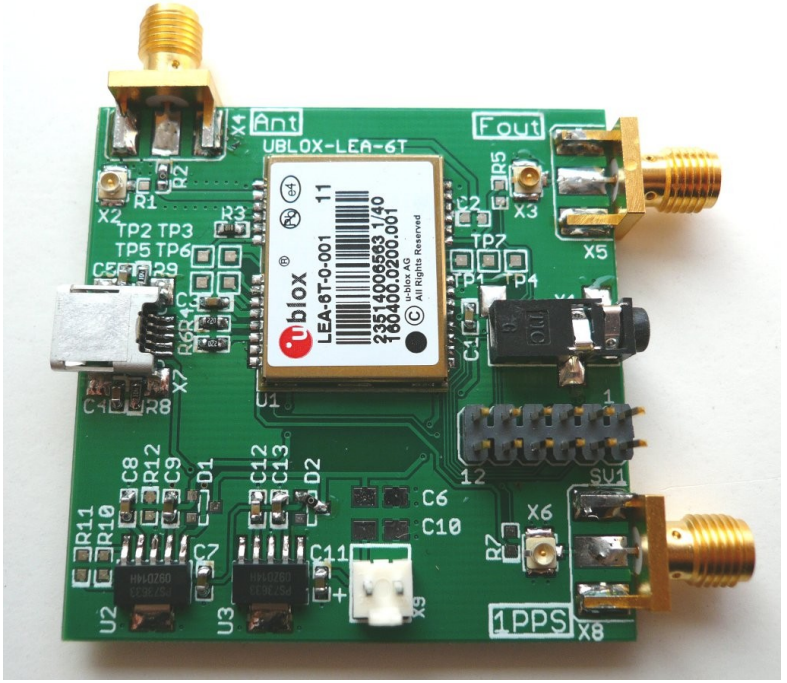
Lightning detection for AERA

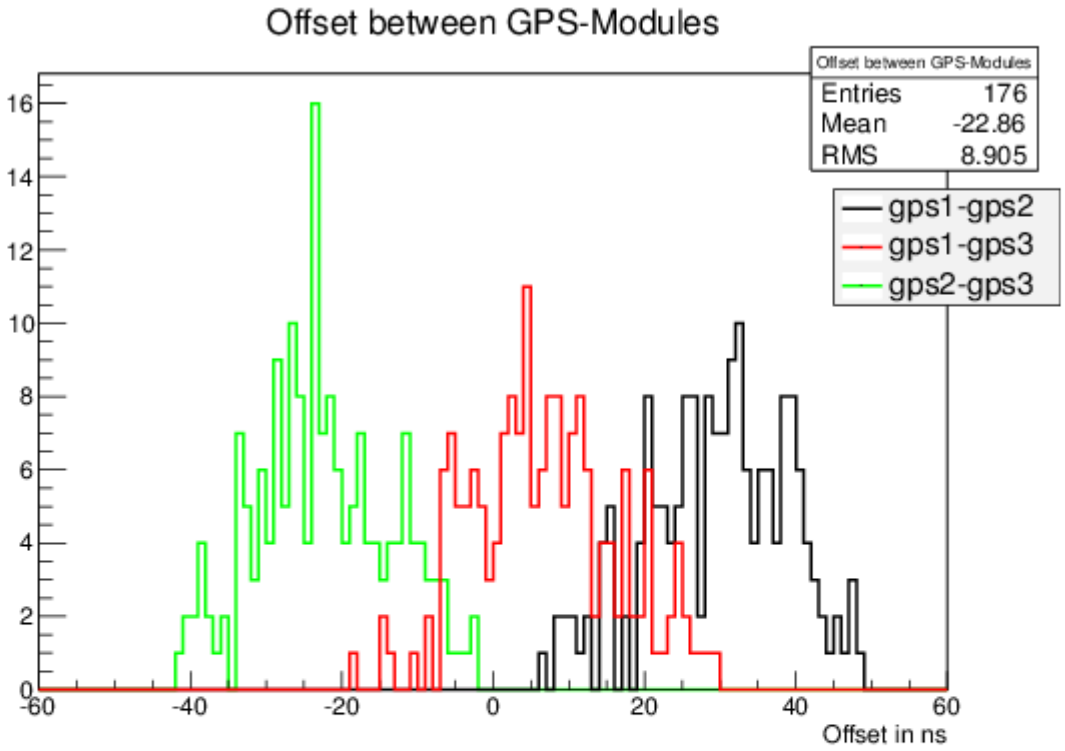
- Lightning data in Auger Mointoring available
- Clear signal e.g. for 9th of March 1:36 am elve



GPS-Extension for Boltek StormTracker

- ublox LEA-6T module
- Read out via USB
- Time Mark External Input from StormTracker Trigger
- Systematic ~ 20 ns
- Resolution ~ 10 ns

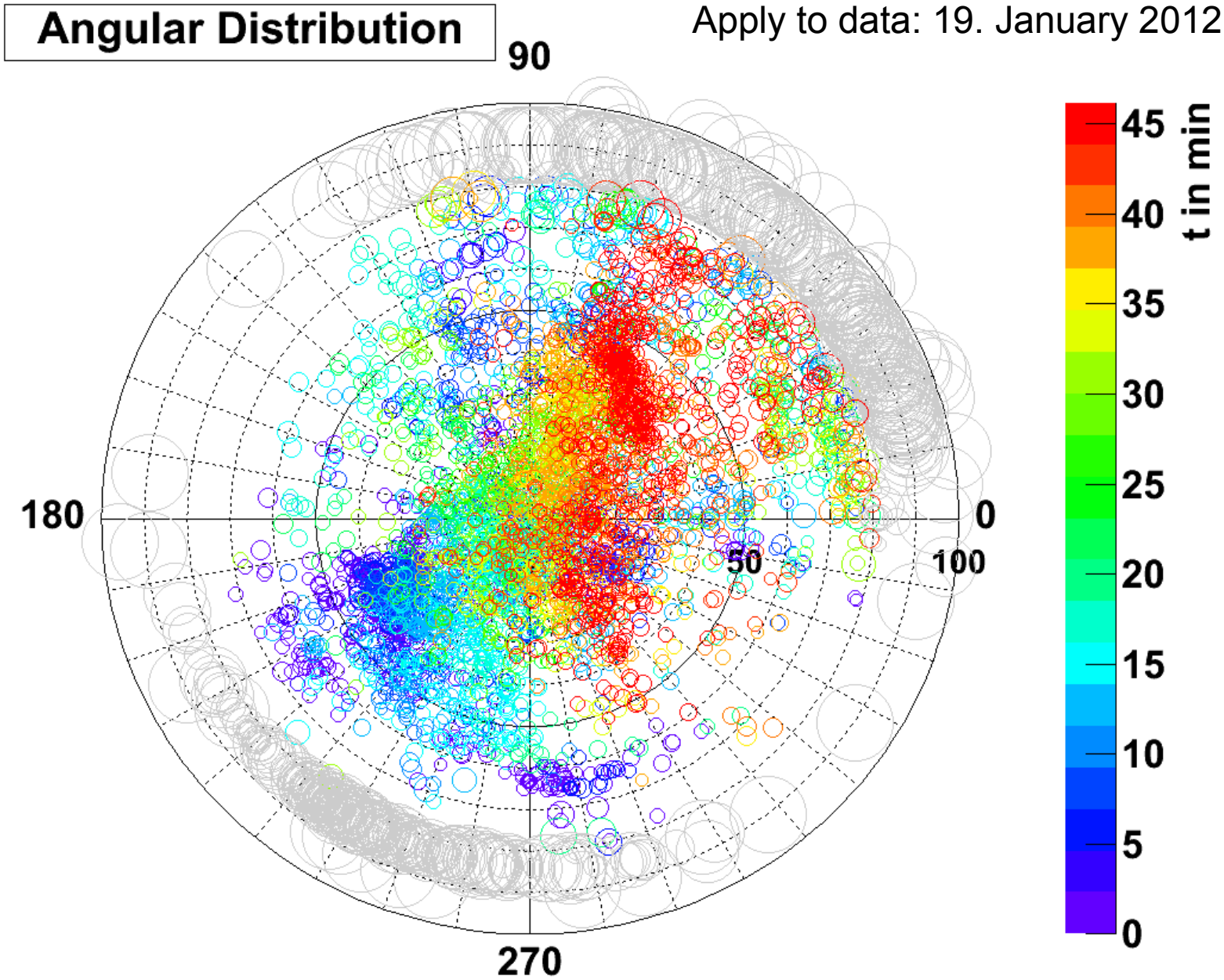




Lightning measuring with AERA

- LMA used 60-66 MHz,
  AERA uses 30-80 MHz
- Lightning measurements with
  180 MHz sampling
- Modification of standard analysis
  for multiple pulses
- Need full buffer (7 sec) read-out

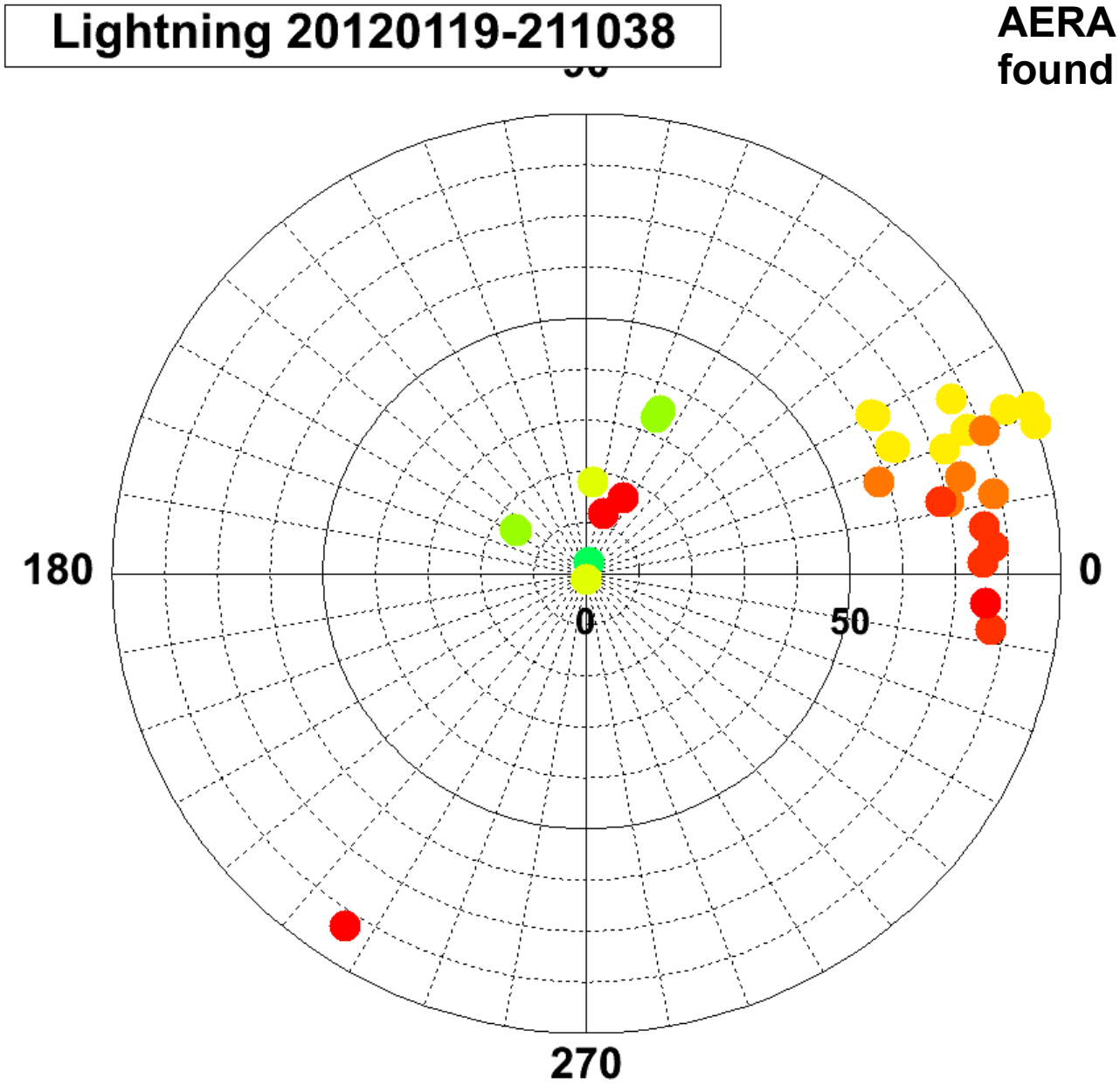
EFM triggered AERA Data



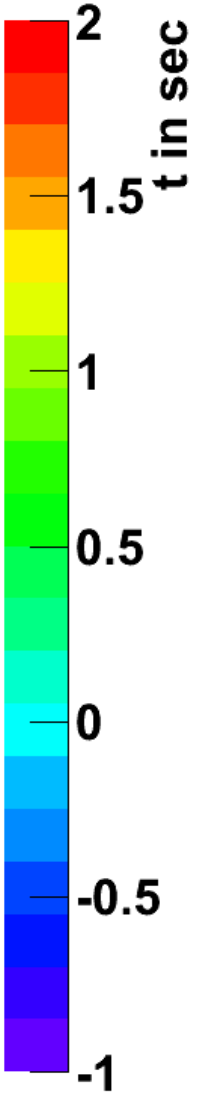
Apply to data: 19. January 2012, 20:39:29 – 21:35:39

Lightning moving over the Array

EFM triggered AERA Data



AERA reconstruction for one Lightning found with E-Field Mill



Lightning correlation with CR

Lightning measurments with:

- Surface Detector,
- E-Field mill,
- Boltek StormTracker,
- Lightning Mapping Array,
- CR Radio Detector

Correlation difficult because needs

- Precise Lightning detection / measurment
- Precise high energy CR (statistics)
- Radio-measurent promising, might do both, but needs verification