Lightnings

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X Astroteilchenschule,
Bärnfeld, 03.10.2013

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Lightnings and Cosmic Rays

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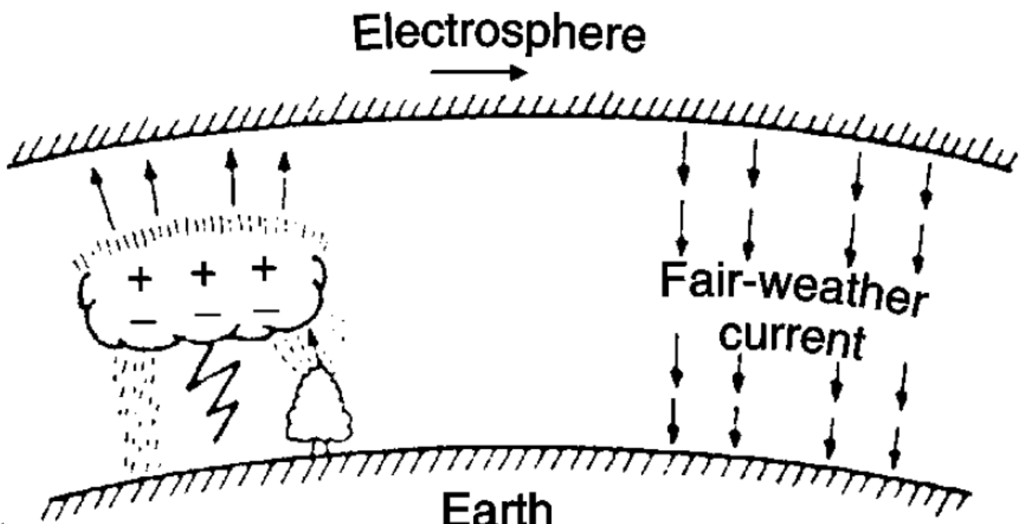
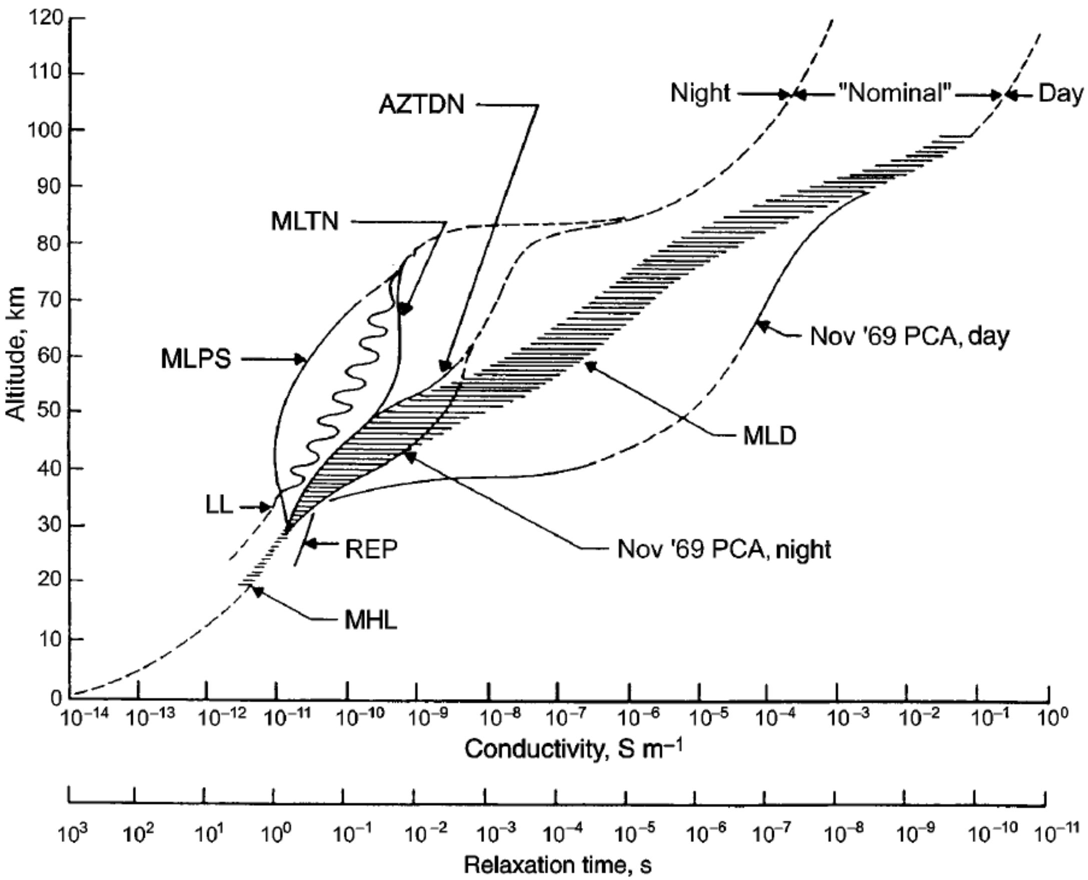
Charge and Curent of the Atmosphere

- Contant positivly charged atmosphere and negatively charged ground
- Potential of ca. 300 kV, most dropping below 20 km
- Current of 1 kA (2 pA/m^2)



Rakov adapted vom Pierce 1974



Conductivity of atmosphere:

10^{-11} S m^{-1} @ 35 km

10^{-14} S m^{-1} @ sea-level

10^{-3} S m^{-1} for ground

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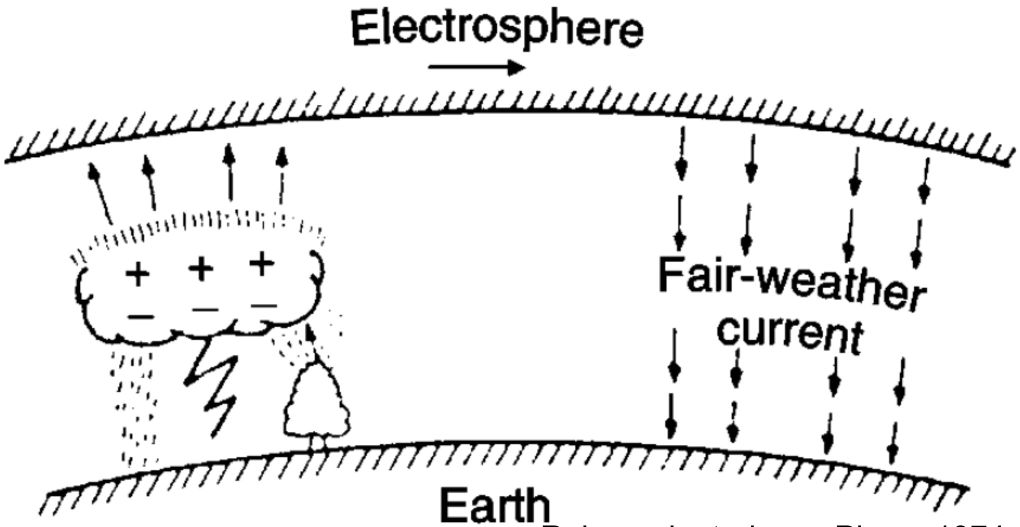

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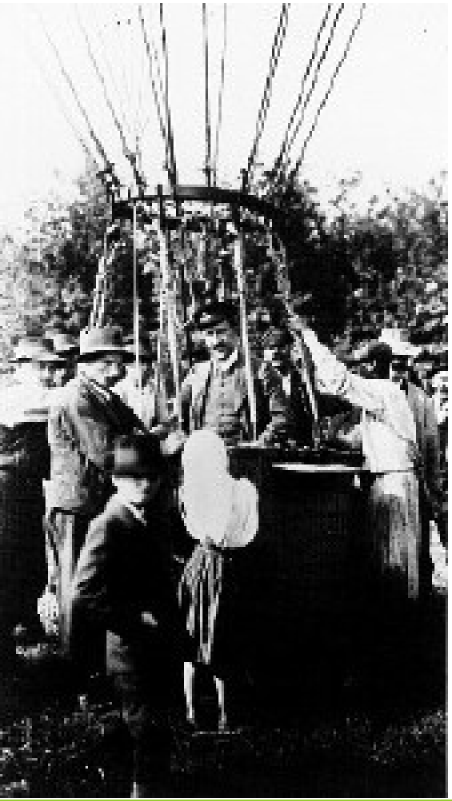

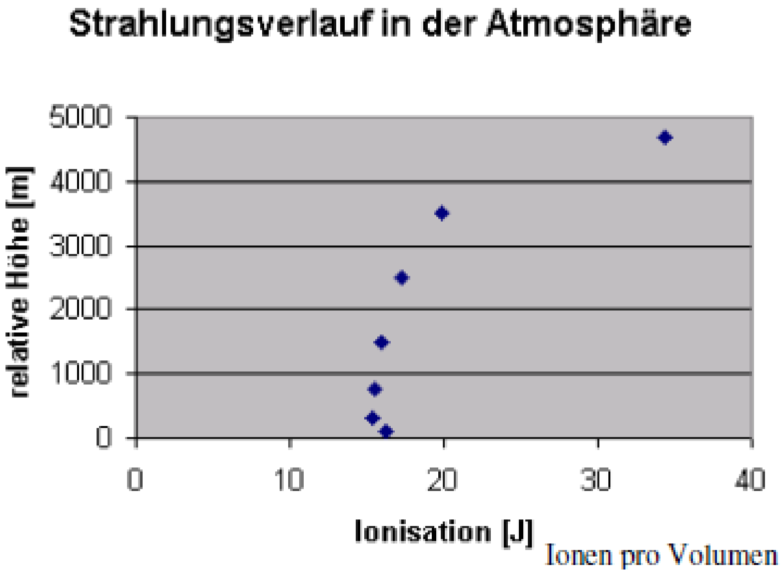

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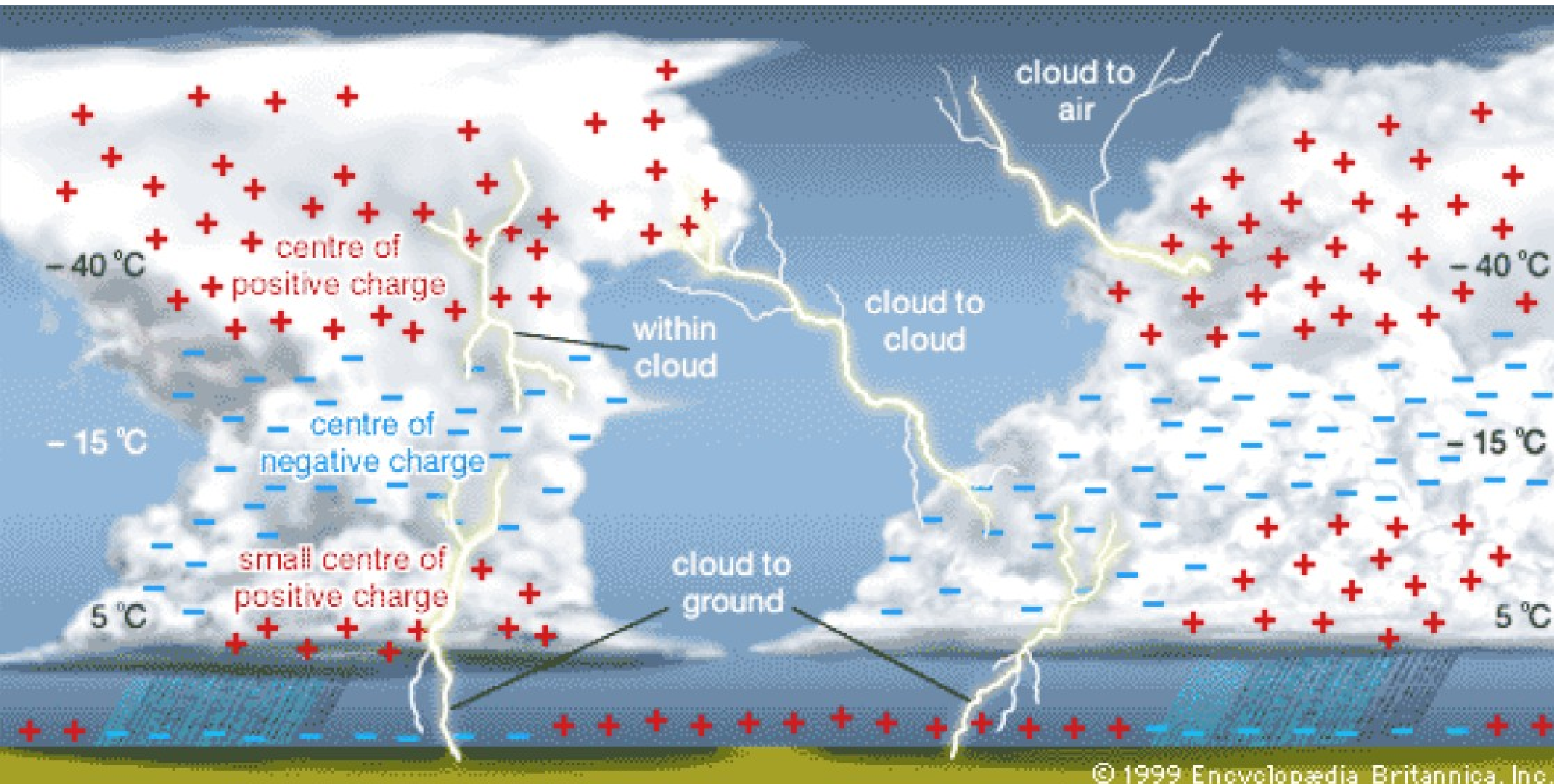
Lightning in a nut-shell

- Inter-/intra-cloud discharges (IC) ca. 75%
- Cloud to Ground lightnings (CG)
- 90% of CG is negative
- Leader duration ca. 1 ms
- Overall lightning ca. 200 ms
- 20% single stroke, usually 3-5
- Charge 20 C, Energy 10^9 to 10^{10} W



Positive Cloud-Ground Lightning

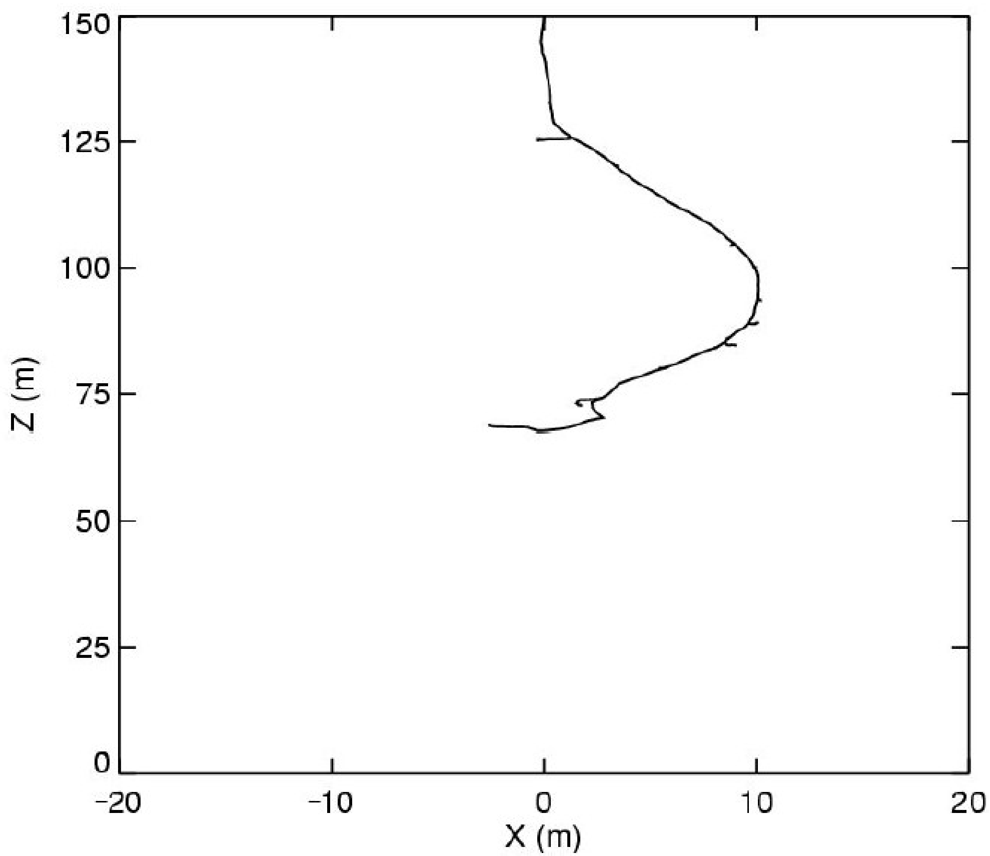
Lightning arcs from the top of a cloud to the horizon off the coast of the Bahamas.

- can be positve
- rare
- usually more powerful
- from farther up in the cloud (16 km)

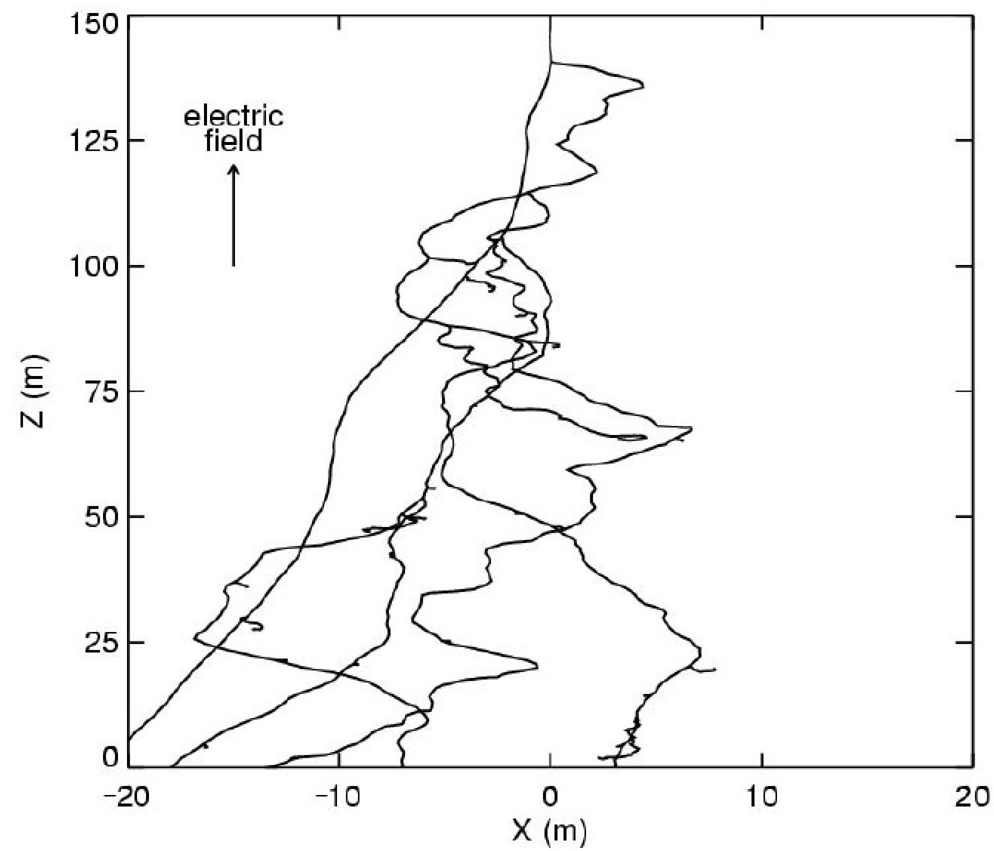
http://environment.nationalgeographic.com/wallpaper/environment/photos/lightning-cloud-ground/cloud-ground-lightning13

Electrons in Air

25 MeV electron in air (1 atm)

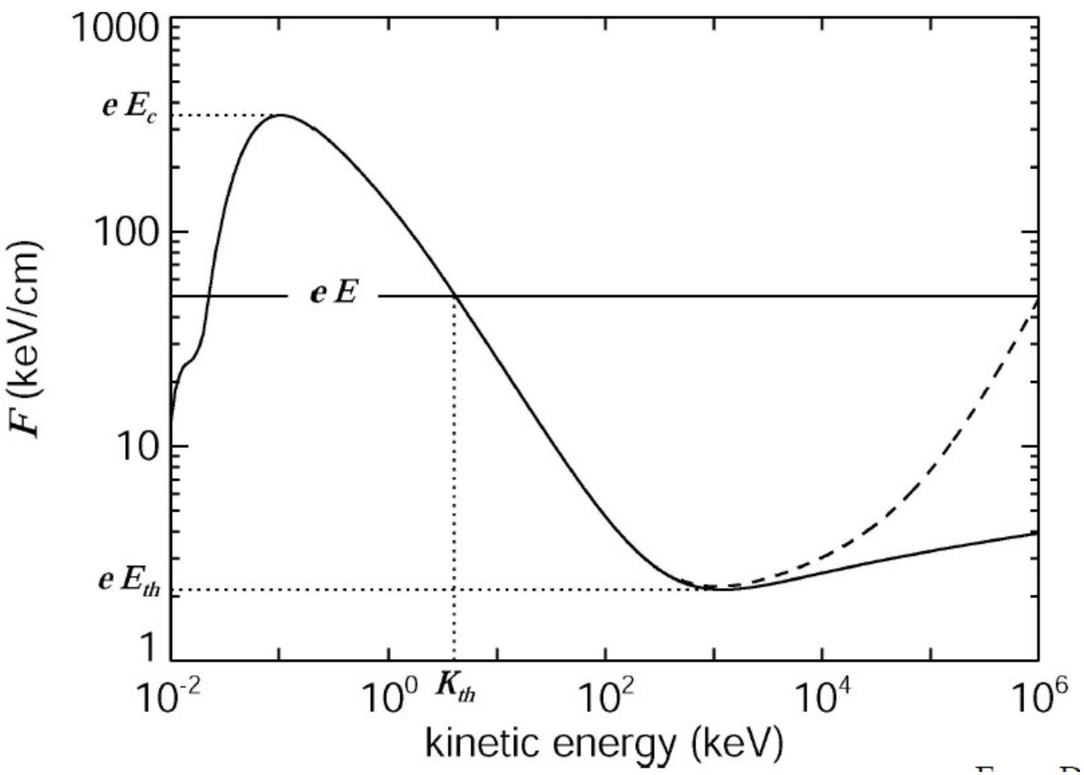


25 MeV electron in air (1 atm) in a 300 kV/m electric field

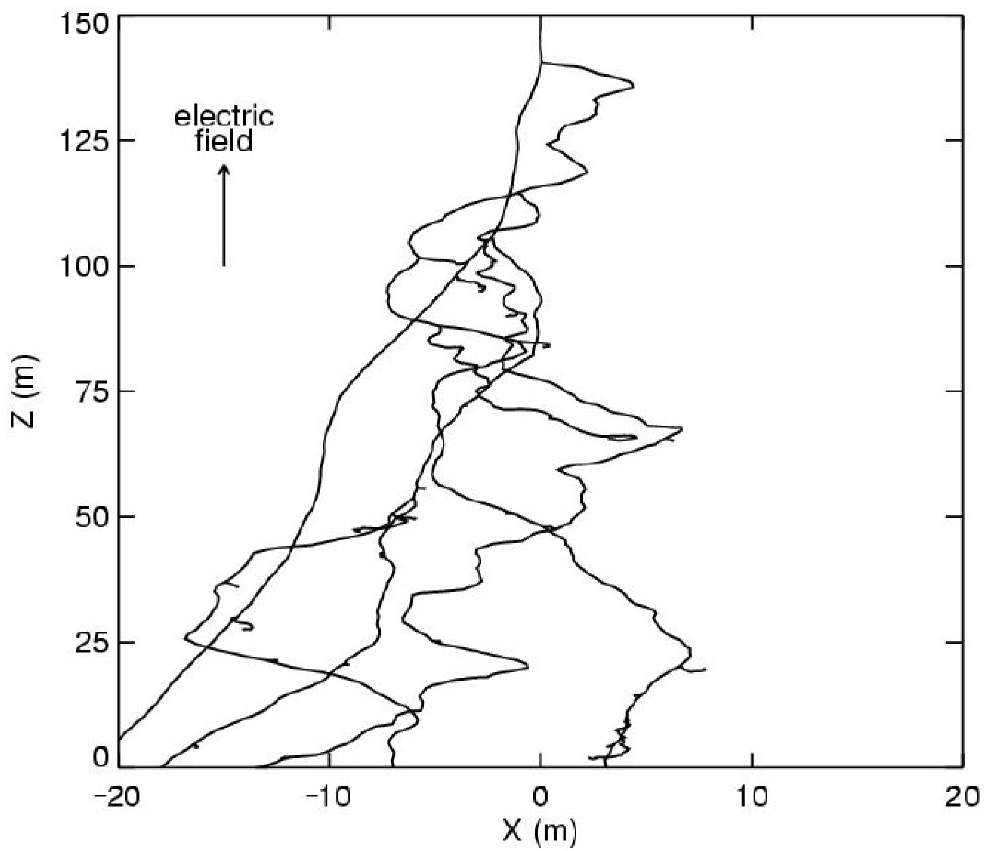


Electrons in Air

Bethe Bloch energy-loss



25 MeV electron in air (1 atm) in a 300 kV/m electric field



Lightning initiation problem

- Decades of in situ electric field observations showed field-strength in cloud of $4x10^5$ V/m (n/n_0 scaled)
- x10 too small for spark (E_b=2.6 10^6 V/m)

Relativistic Runaway Electron Avalanche:

- the electrons gain more energy than they loose by interaction in air
- E_{RREA} $2.84x10^5$ V/m
- X-ray emission and positions in avalanche backpropagate may feedback the seed electrons

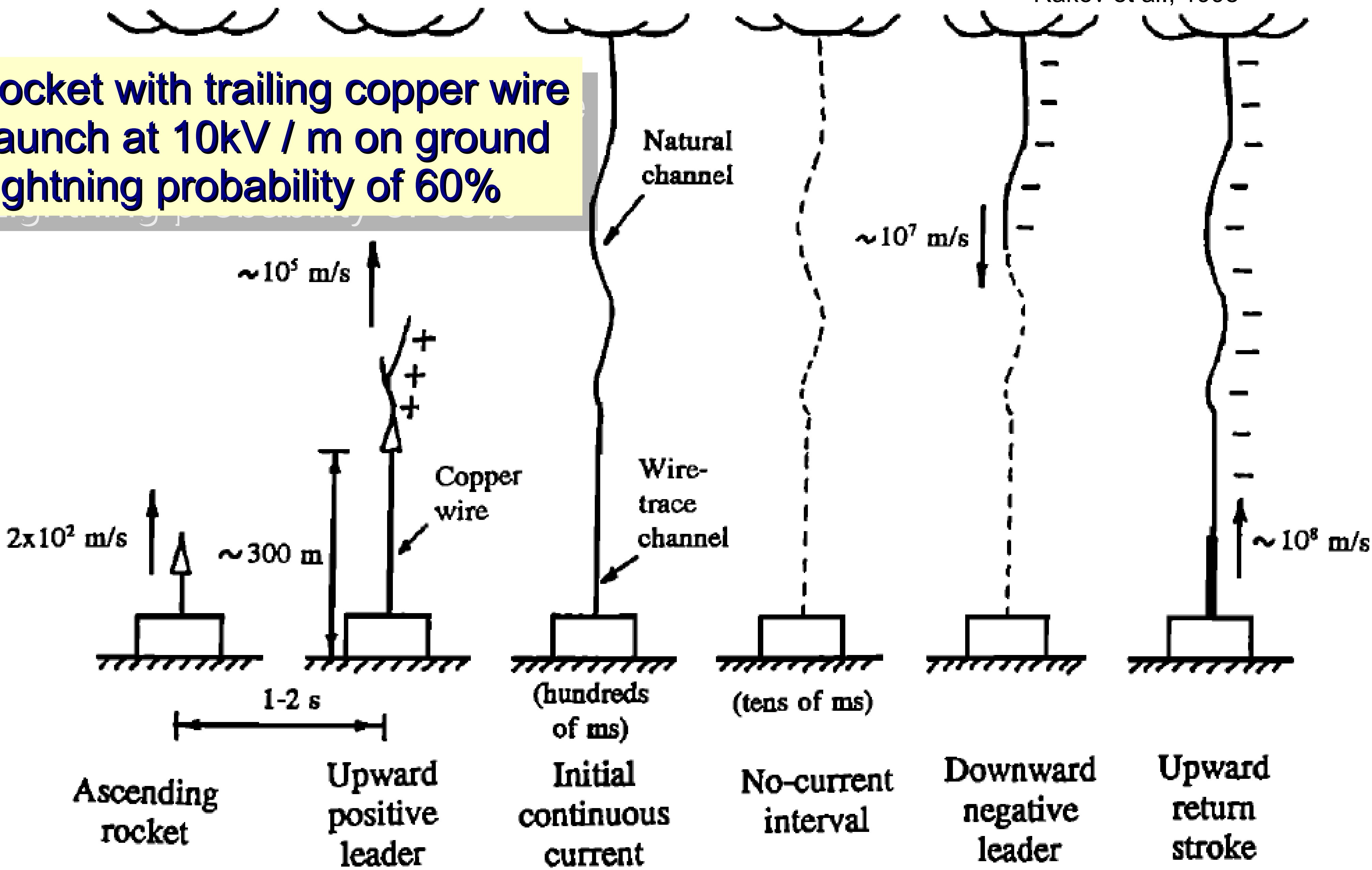
Rocket ignited lightning

Movies from:
http://www.lightning.ece.ufl.edu/

Rocket ignited lightning

Rakov et al., 1998

Rocket with trailing copper wire
Launch at 10kV / m on ground
Lightning probability of 60%

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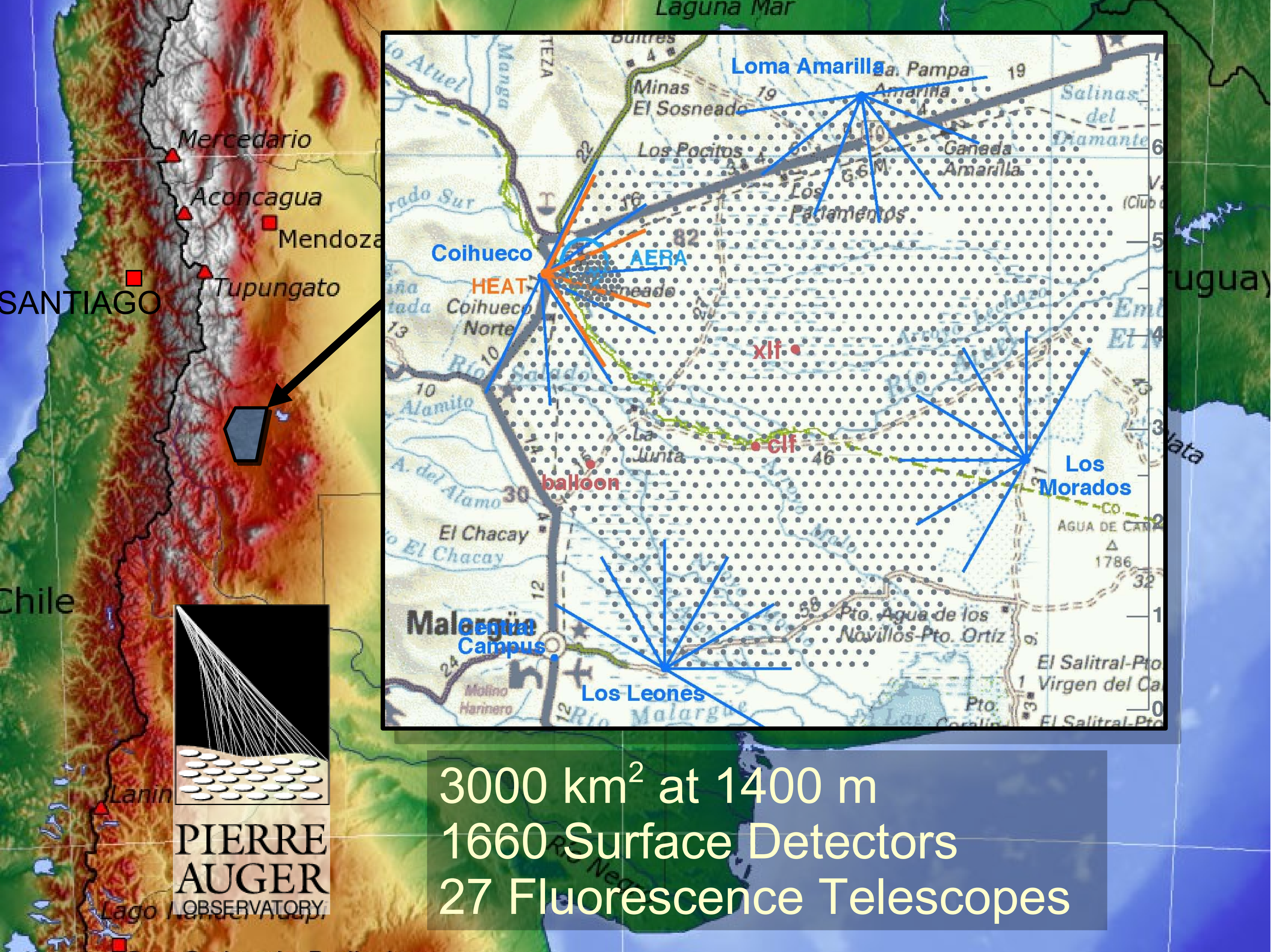
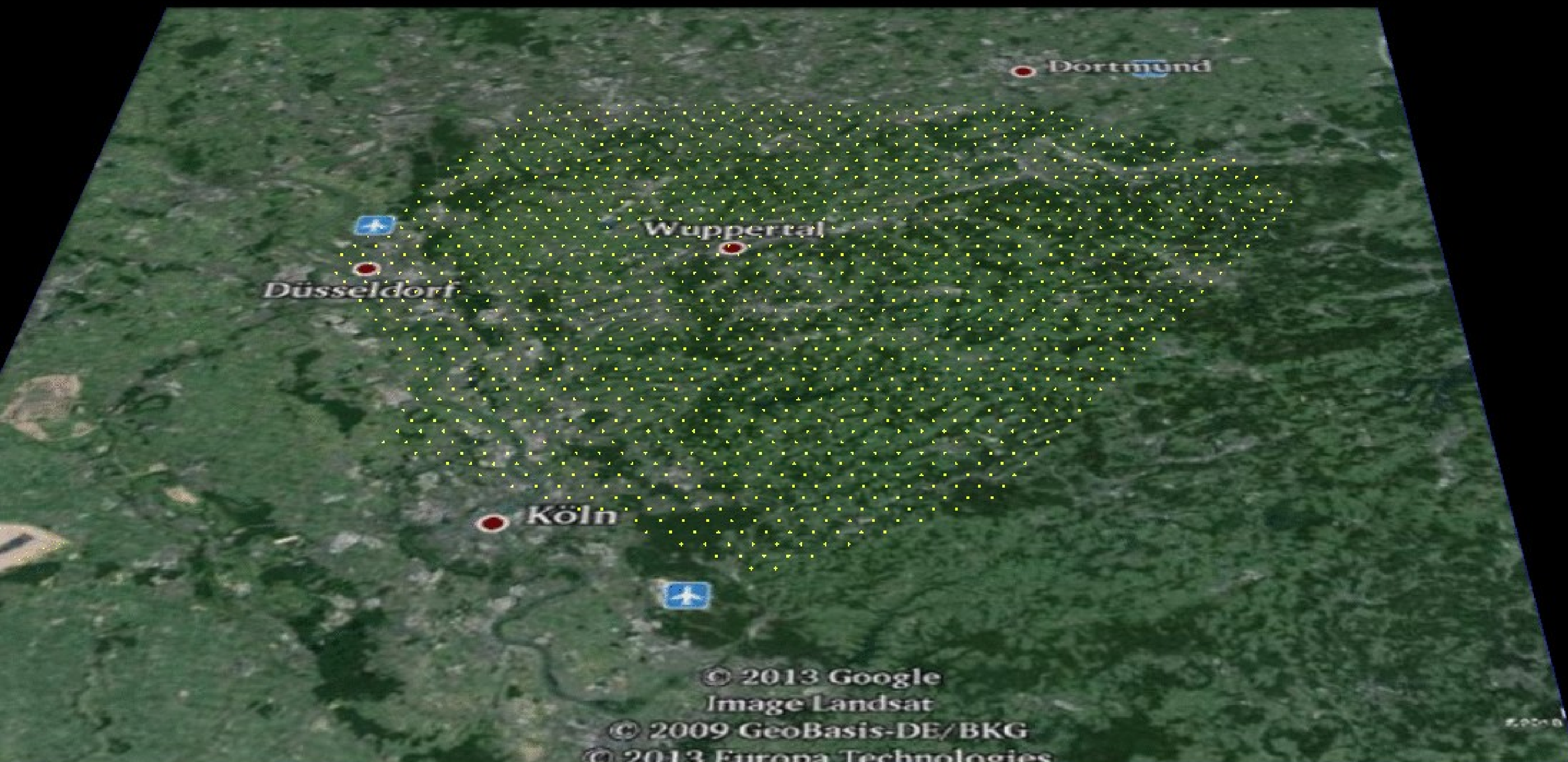
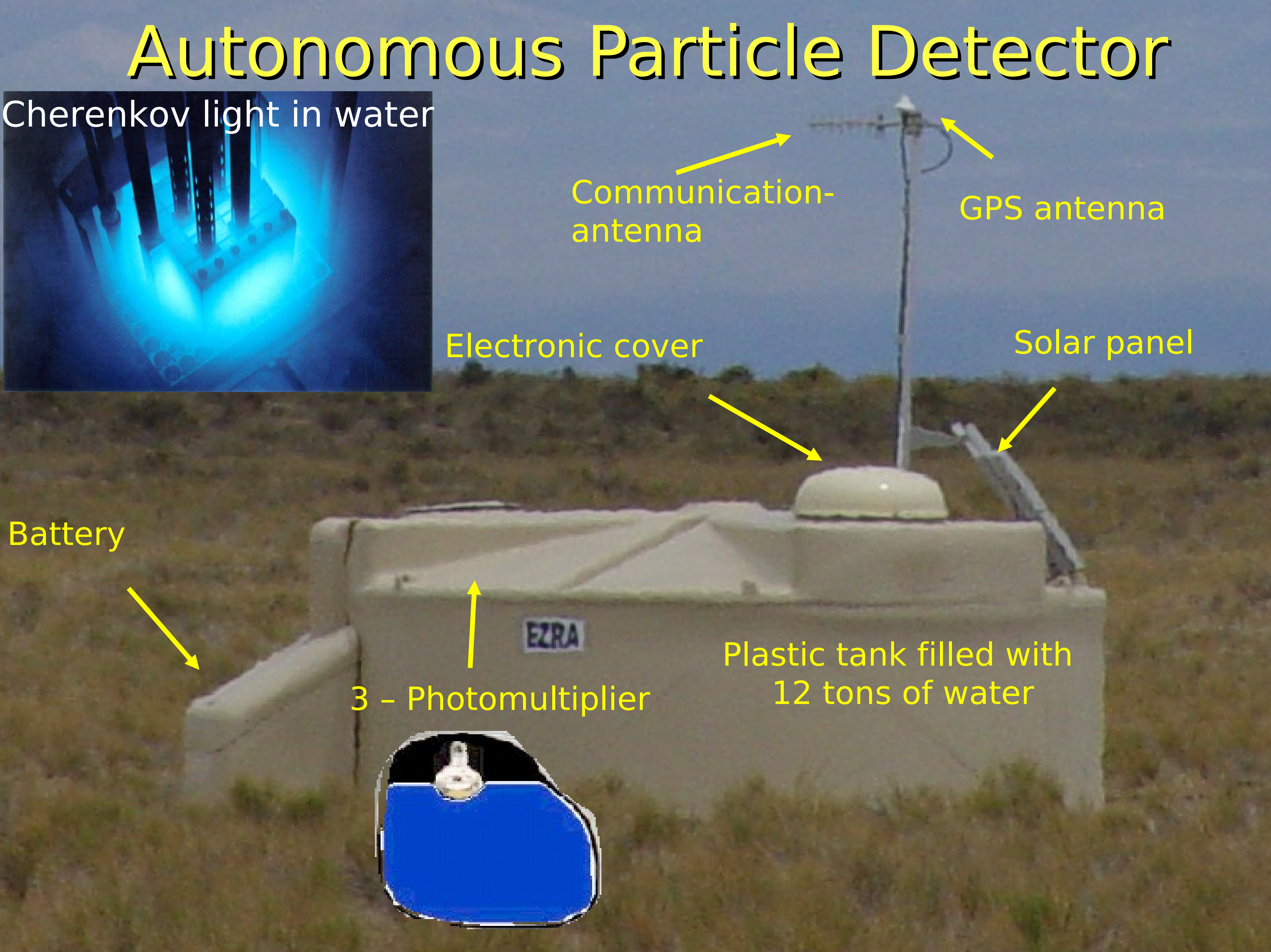
Lightnings and Cosmic Rays
at LOPES and AUGER


Mercedario
Aconcagua
Mendoza
SANTIAGO
Tupungato
Chile
Lanin
Laguna Mar
Loma Amarilla
Coihueco
HEAT
AERA
xlf
clf
balloon
Los Morados
Central Campus
Los Leones
Malargüe
PIERRE AUGER OBSERVATORY
3000 km² at 1400 m
1660 Surface Detectors
27 Fluorescence Telescopes

EAS over Wuppertal

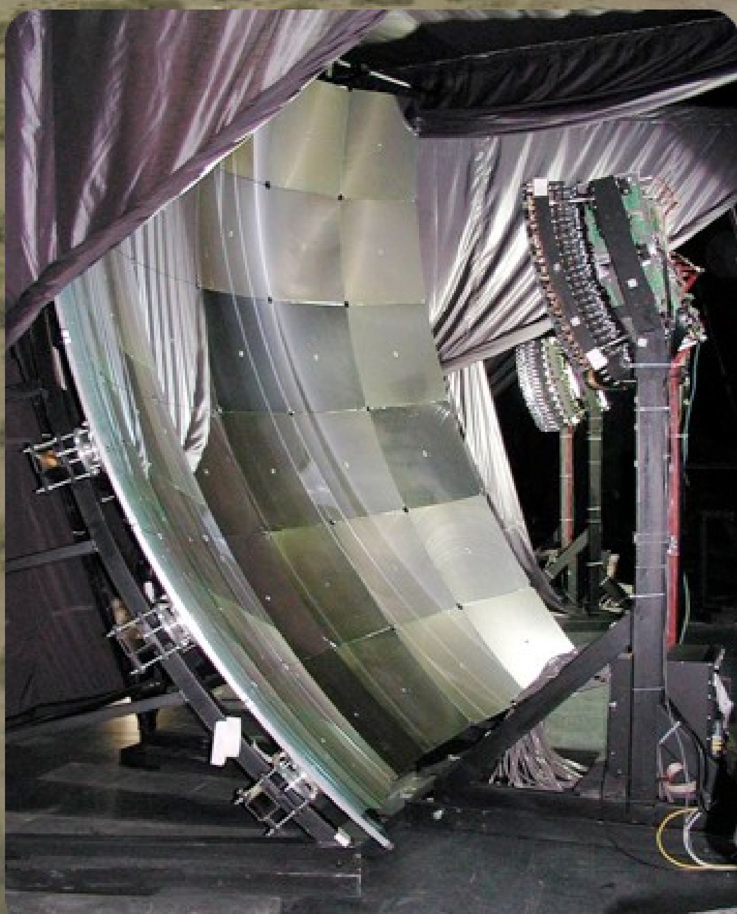


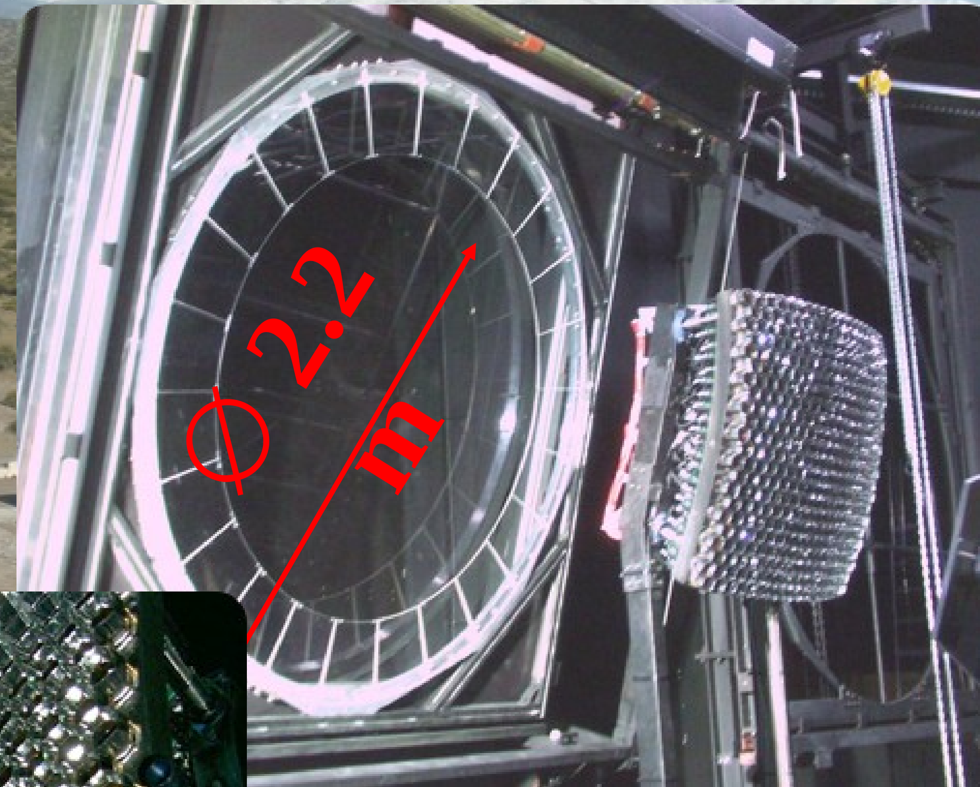
10 EeV proton shower at 75 degree
S. Querchfeld; visualizations Univ. Chicago; shower S. Sciutto's AIRES

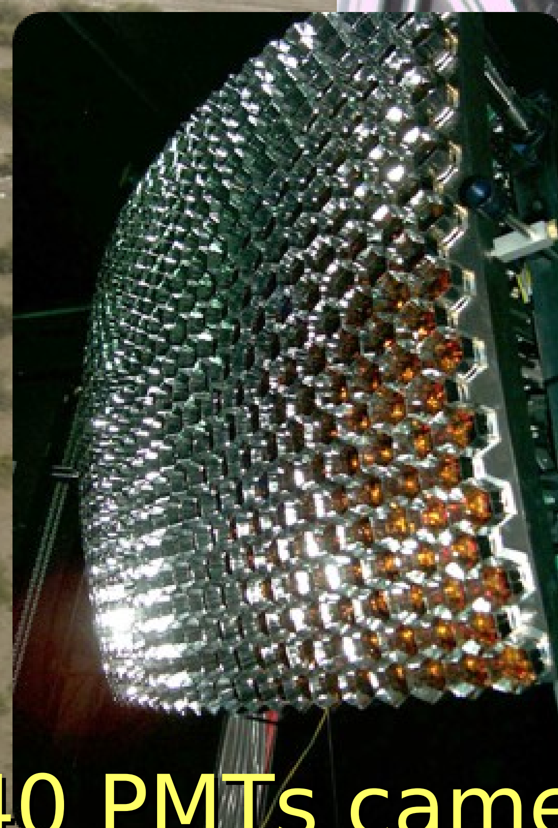

Autonomous Particle Detector
Cherenkov light in water
Communication-
antenna
GPS antenna
Electronic cover
Solar panel
Battery
EZRA
Plastic tank filled with
12 tons of water
3 – Photomultiplier

Camera System

24+3 telescopes
12 m² mirror
30°x30° field of view
440 PMT/camera
10 Mio pictures/s



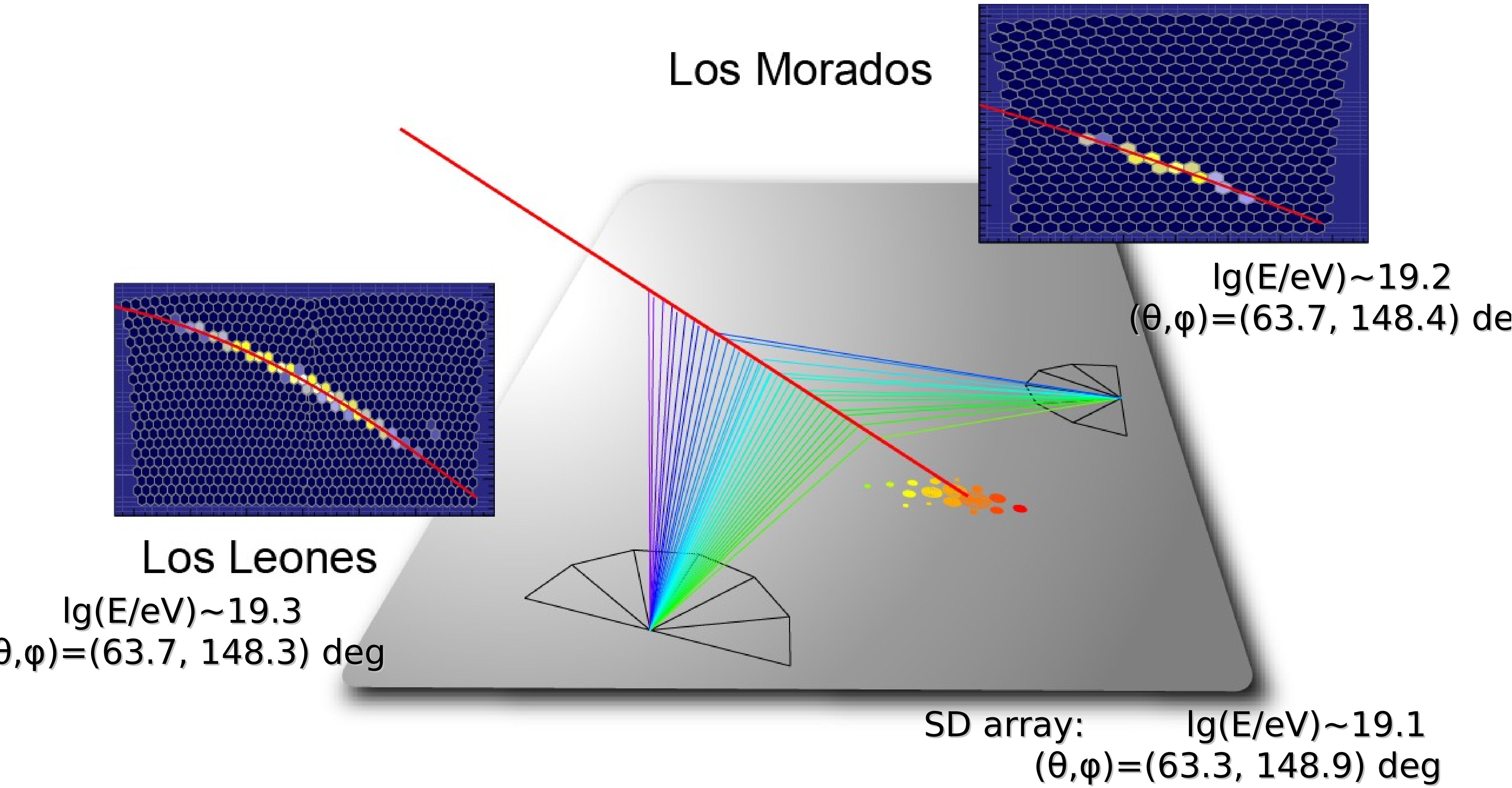




440 PMTs camera

Hybrid measurement of extensive air shower

Stereo observation of an EAS



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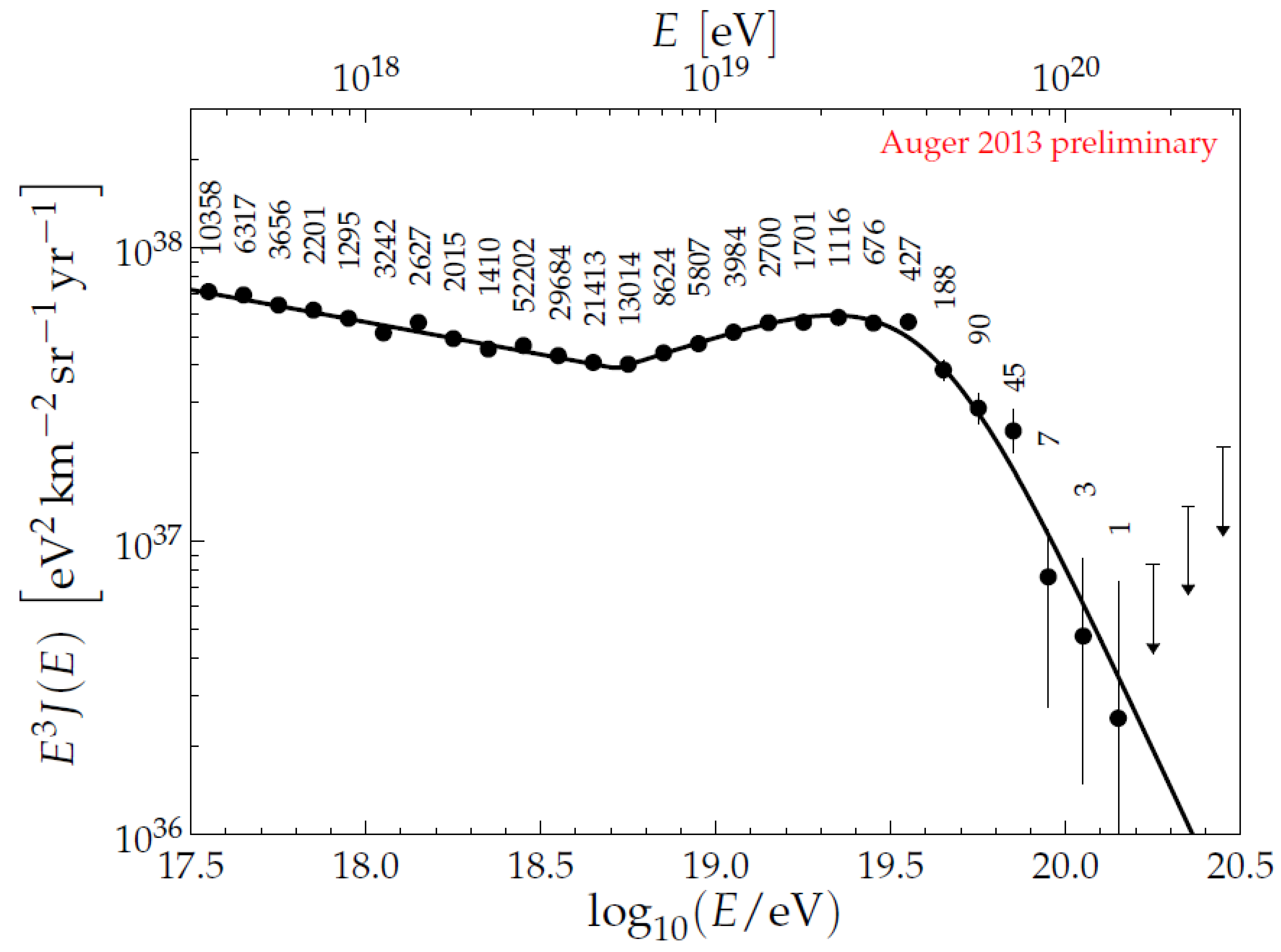
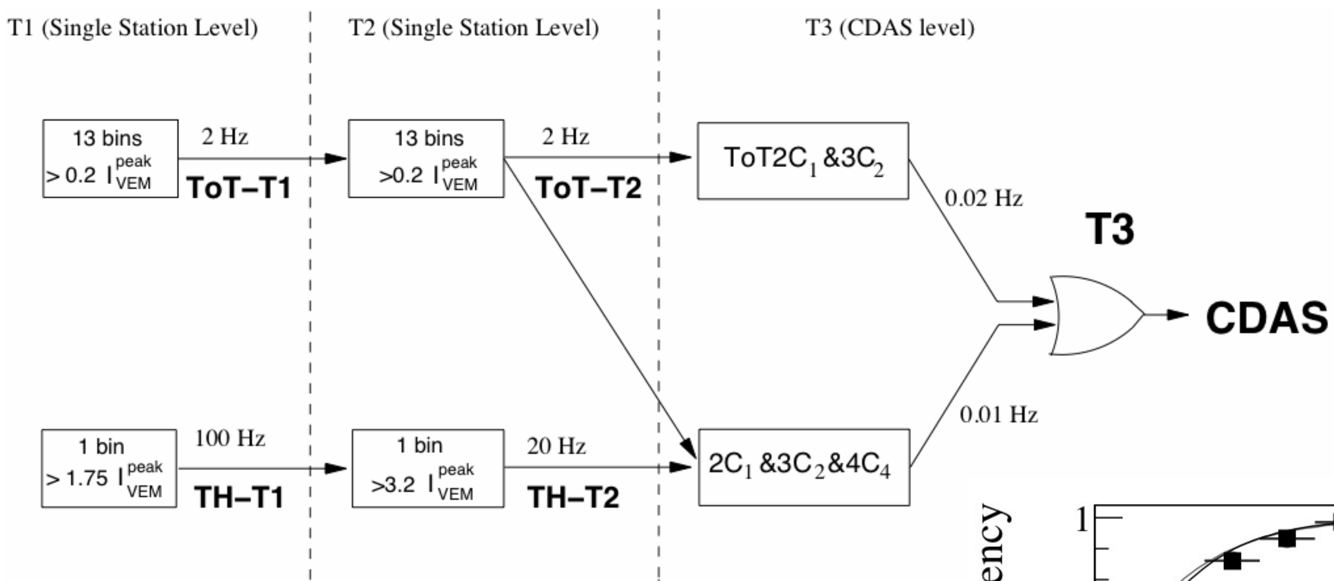
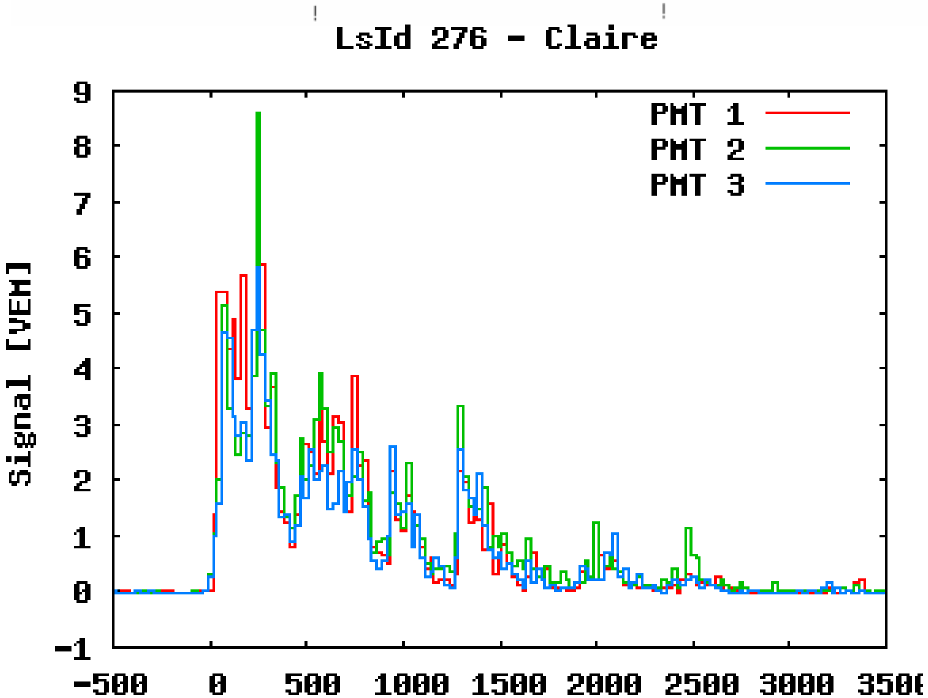
Energy spectrum to the highest energies

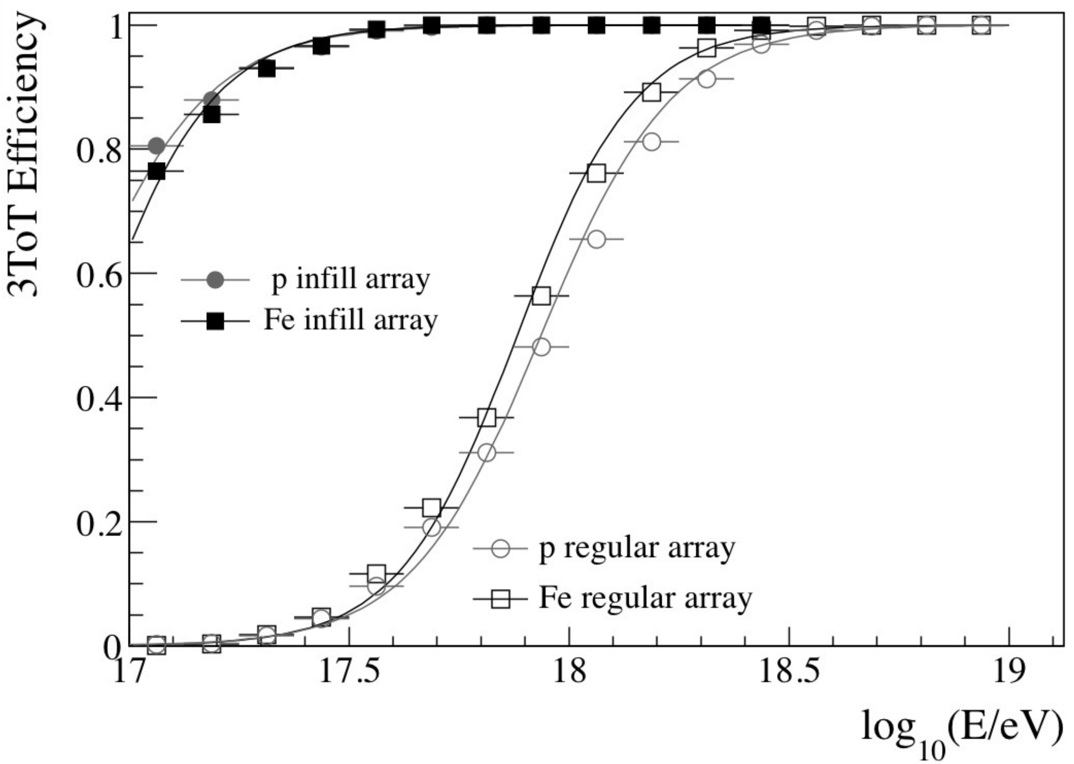


SD Trigger efficiency

SD-Trace:
40 MHz sampling

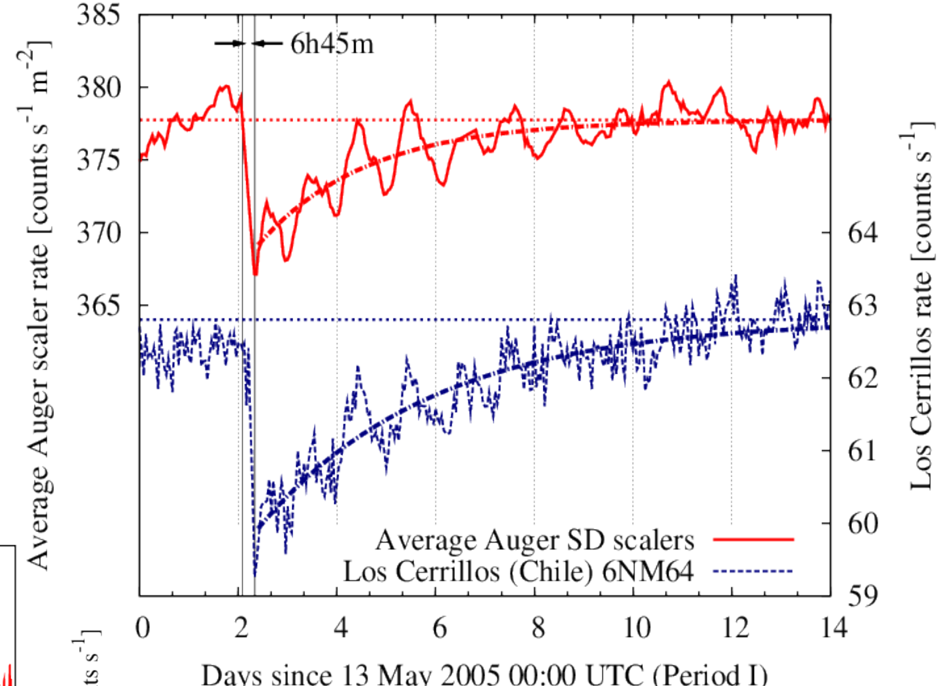


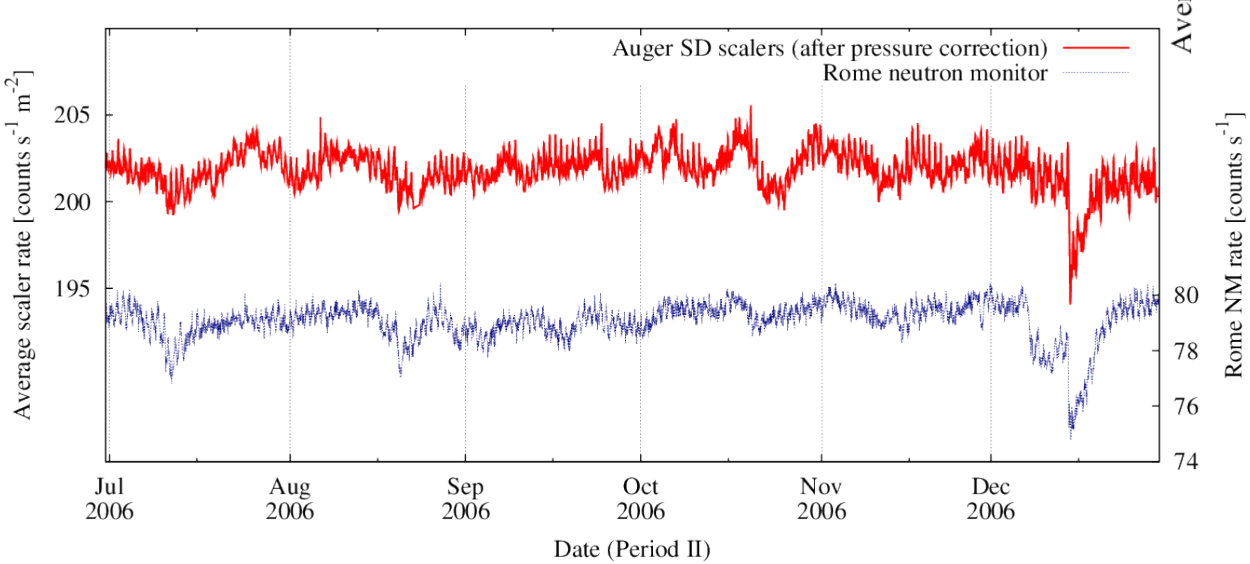




SD-Scaler Measurments

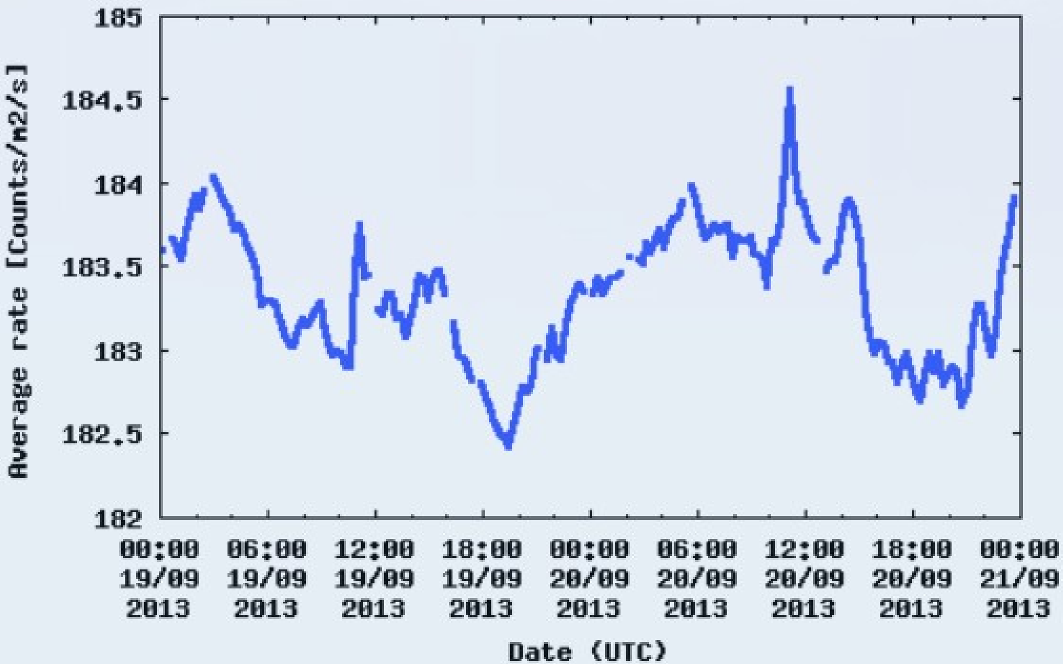
- JINST 6 P01003 (2011)
- Count 12 ns bins with signal above 3 FADC counts (dE/dx ~ 15MeV) and upper bound of 20 FADC counts (~ 100MeV) to remove muon background for GRBs searches
- Average ~ 2 kHz
- Good correlation with neutron monitors
- “Space weather”

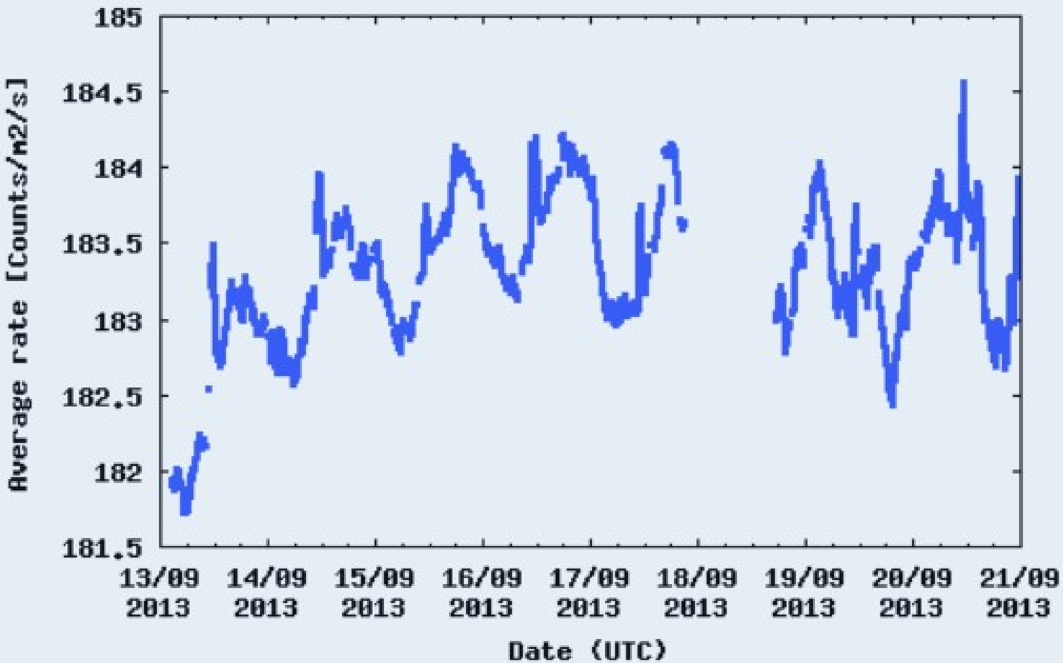




Should you use these data for any publication, acknowledgement to the Pierre Auger Observatory should be given and JINST 6 P01003 (2011) should be cited. You can also download an ascii file with all the dataset.

Latest scaler data





Pierre Auger Observatory
Public Event Explorer

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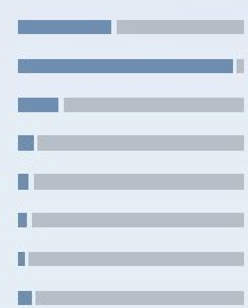
s data available to the
cted since 2004, and is

r an event with the event
can also download an ascii

.7 EeV. Last event is
, UTC Time.

access indicated (larger



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)

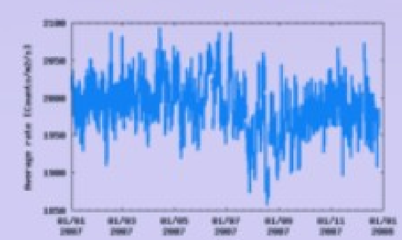
Show 10 Events

Search

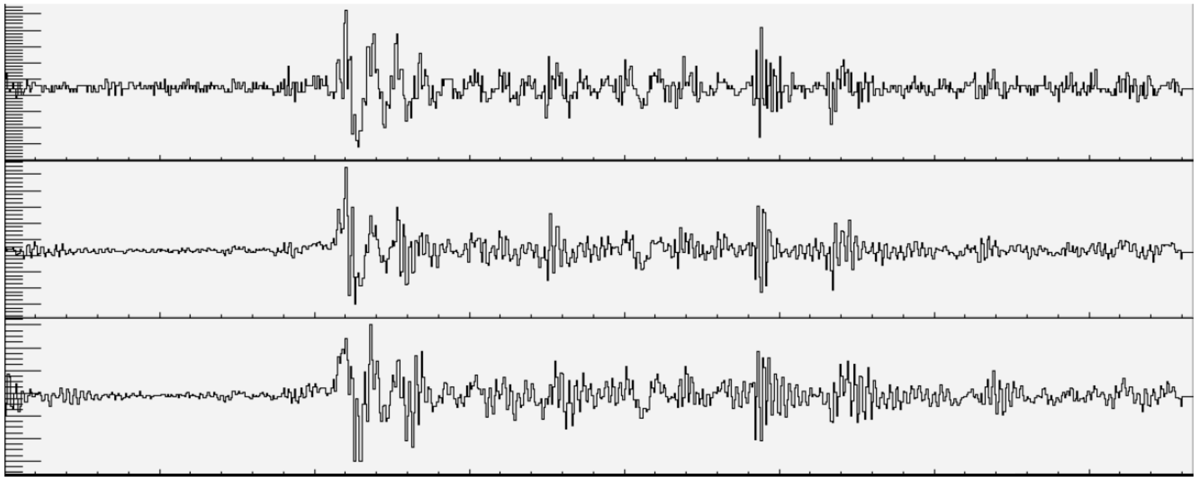
Go to event Id 4128900

Size of the Pierre Auger Observatory

Space Weather page



SD-Scaler Measurments



SD-Trace of a lightning event

Scalers count many “particles”

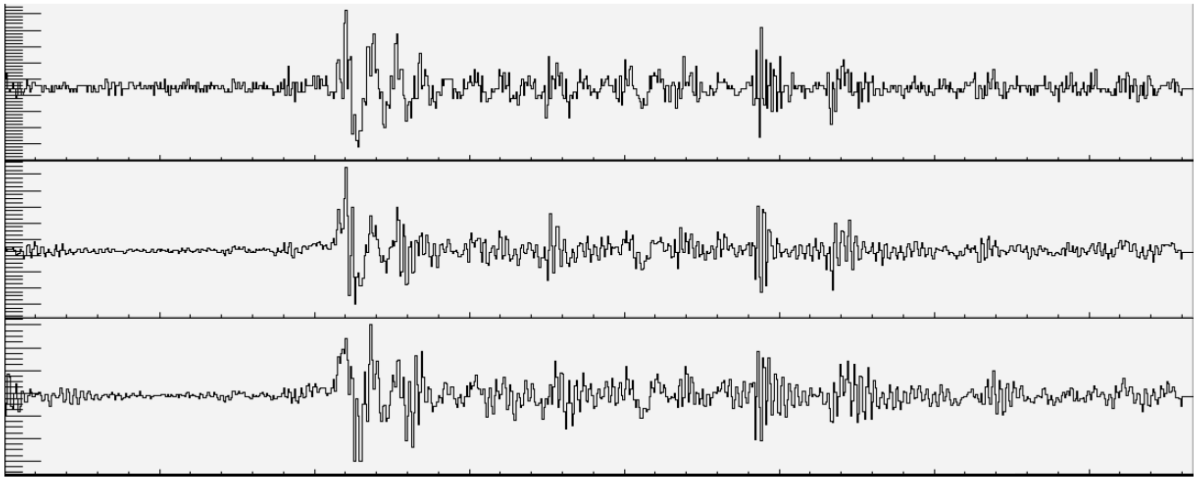
Analysis of Traces give better lightning-indicator

SD-Scaler Measurments

Xavier Bertou

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

SD-Scaler Measurments



SD-Trace of a lightning event

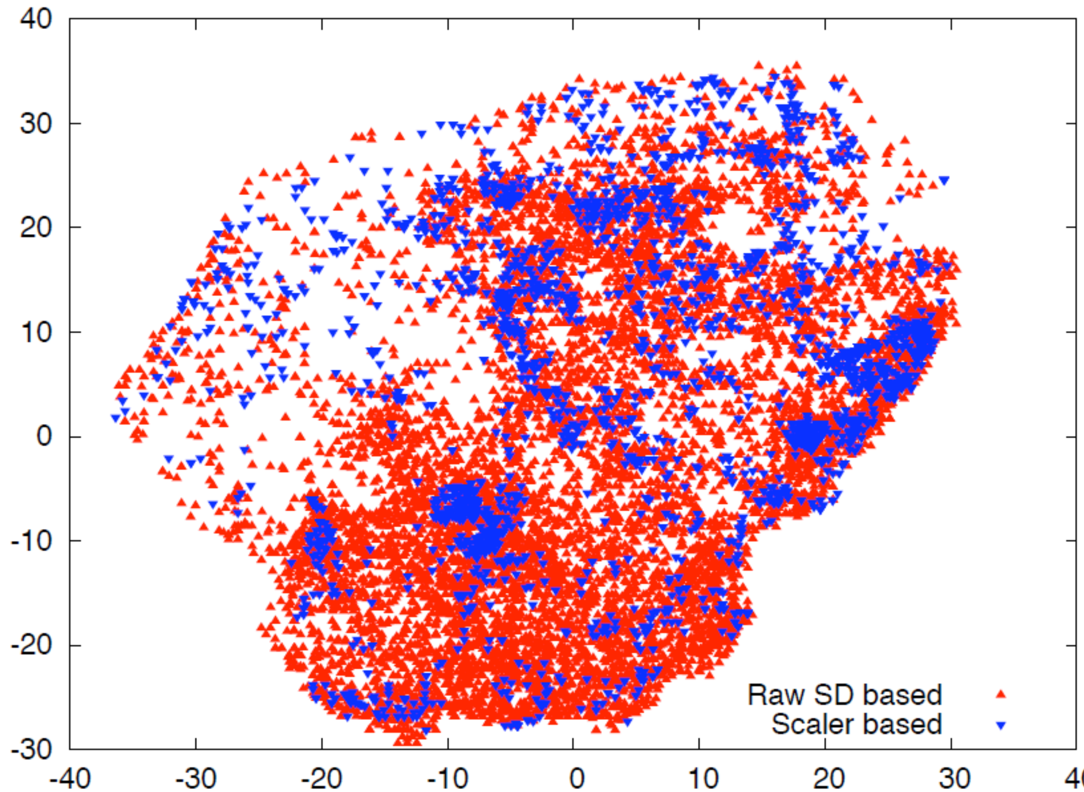
Scalers count many “particles”

Analysis of Traces give better lightning-indicator

Preliminary result:

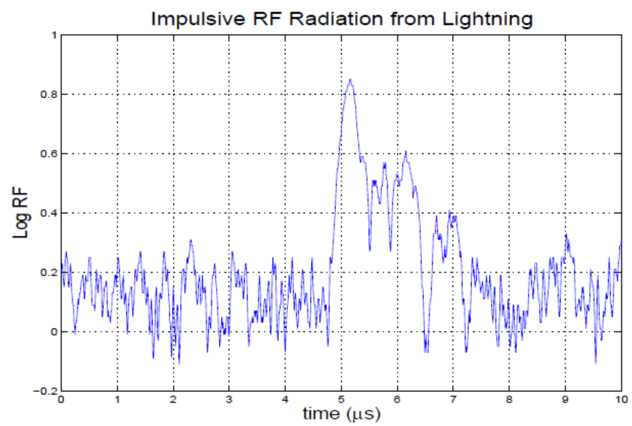
No correlation with Auger-Events due to high energy-threshold log(E/eV)>18.5

Xavier Bertou

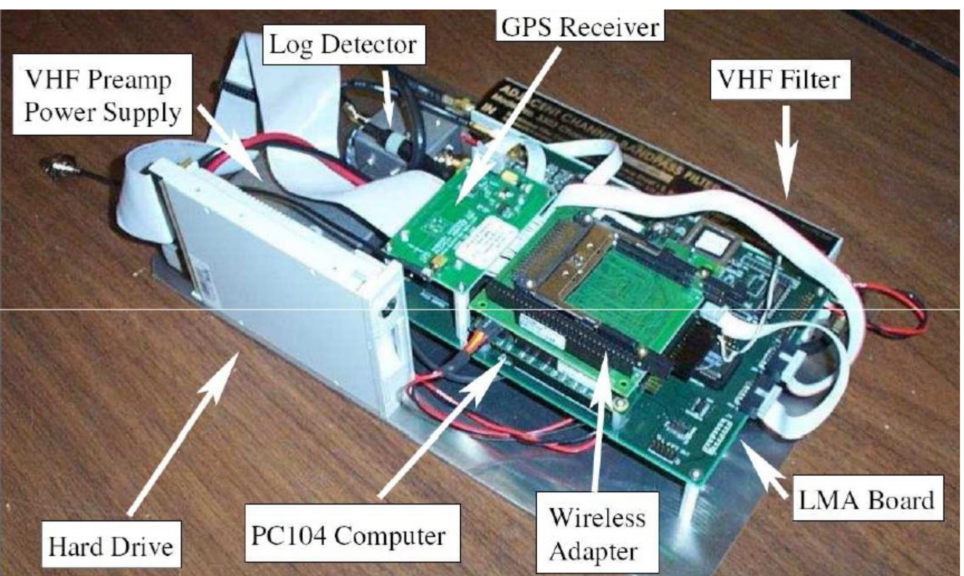


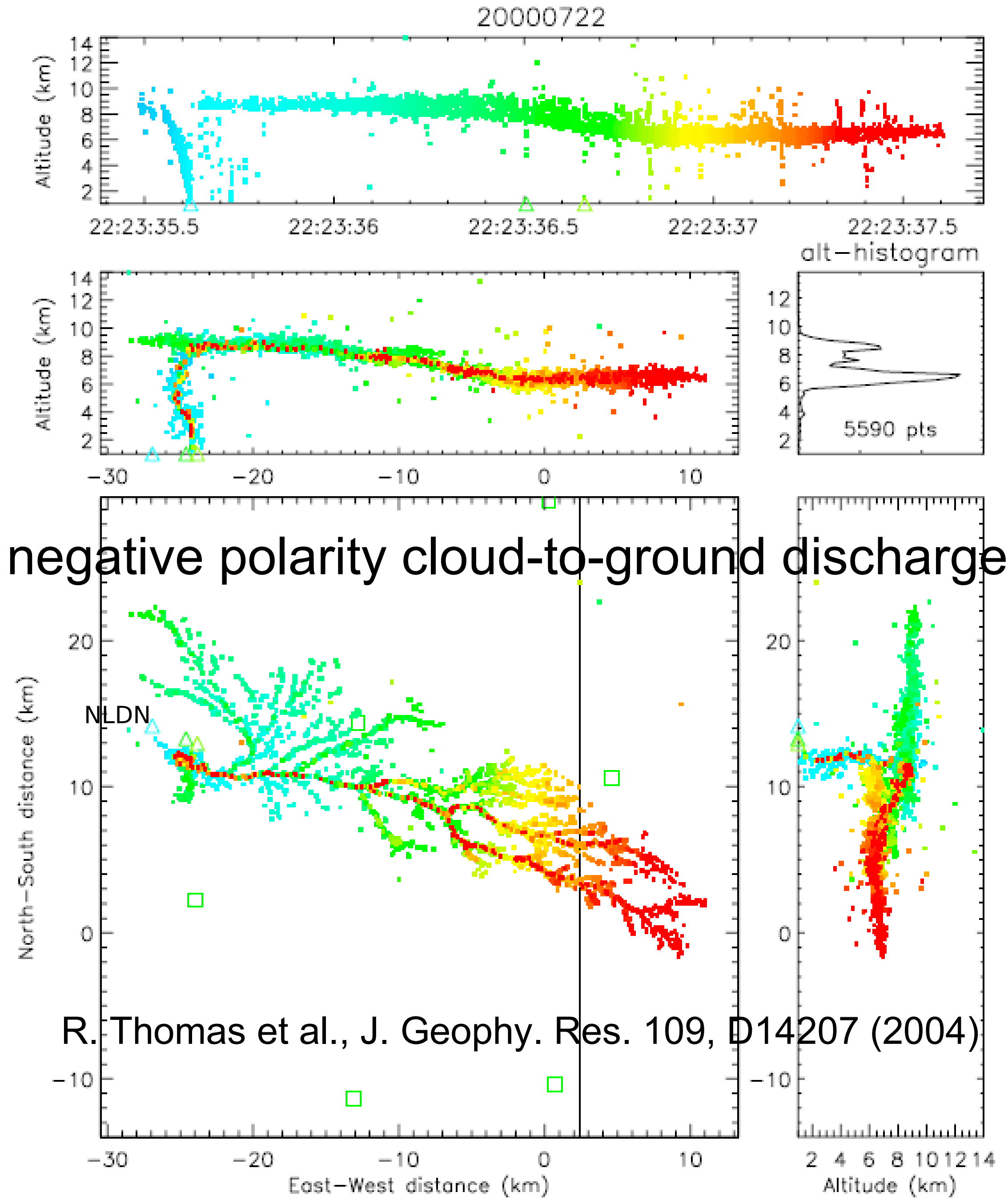
Lightning Detectors

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



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

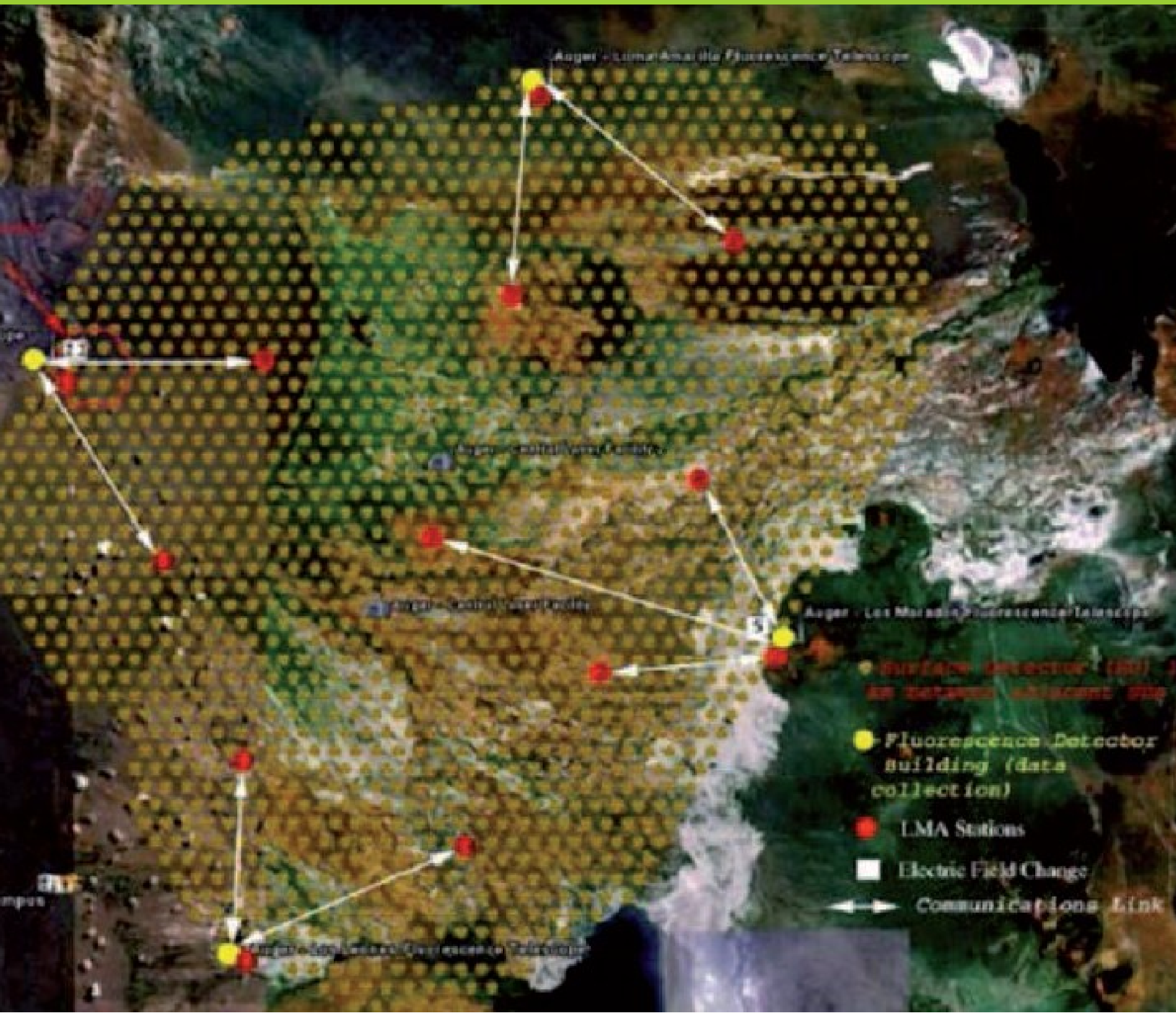


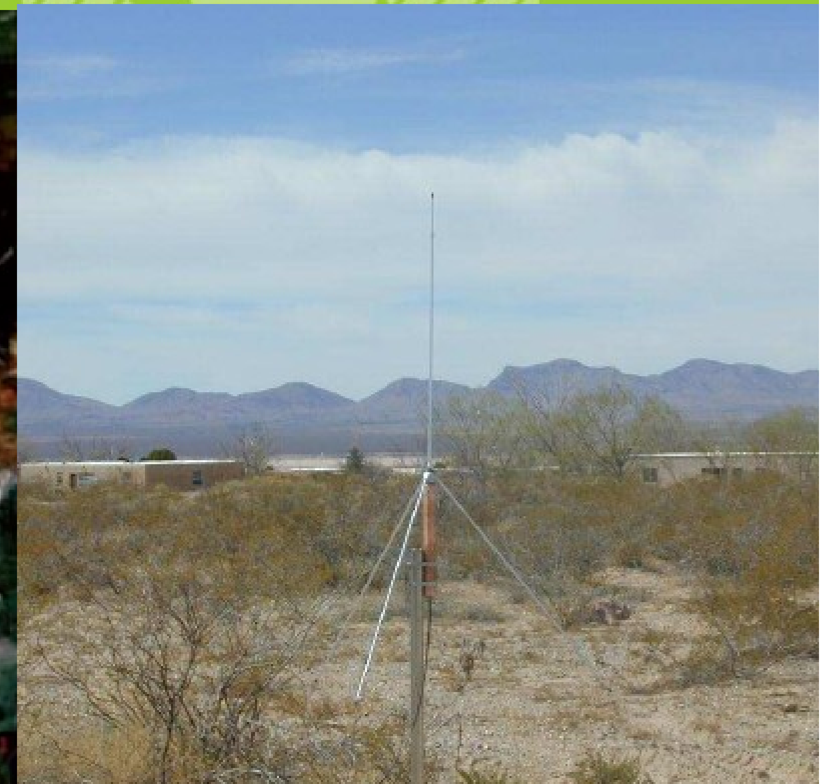


negative polarity cloud-to-ground discharge

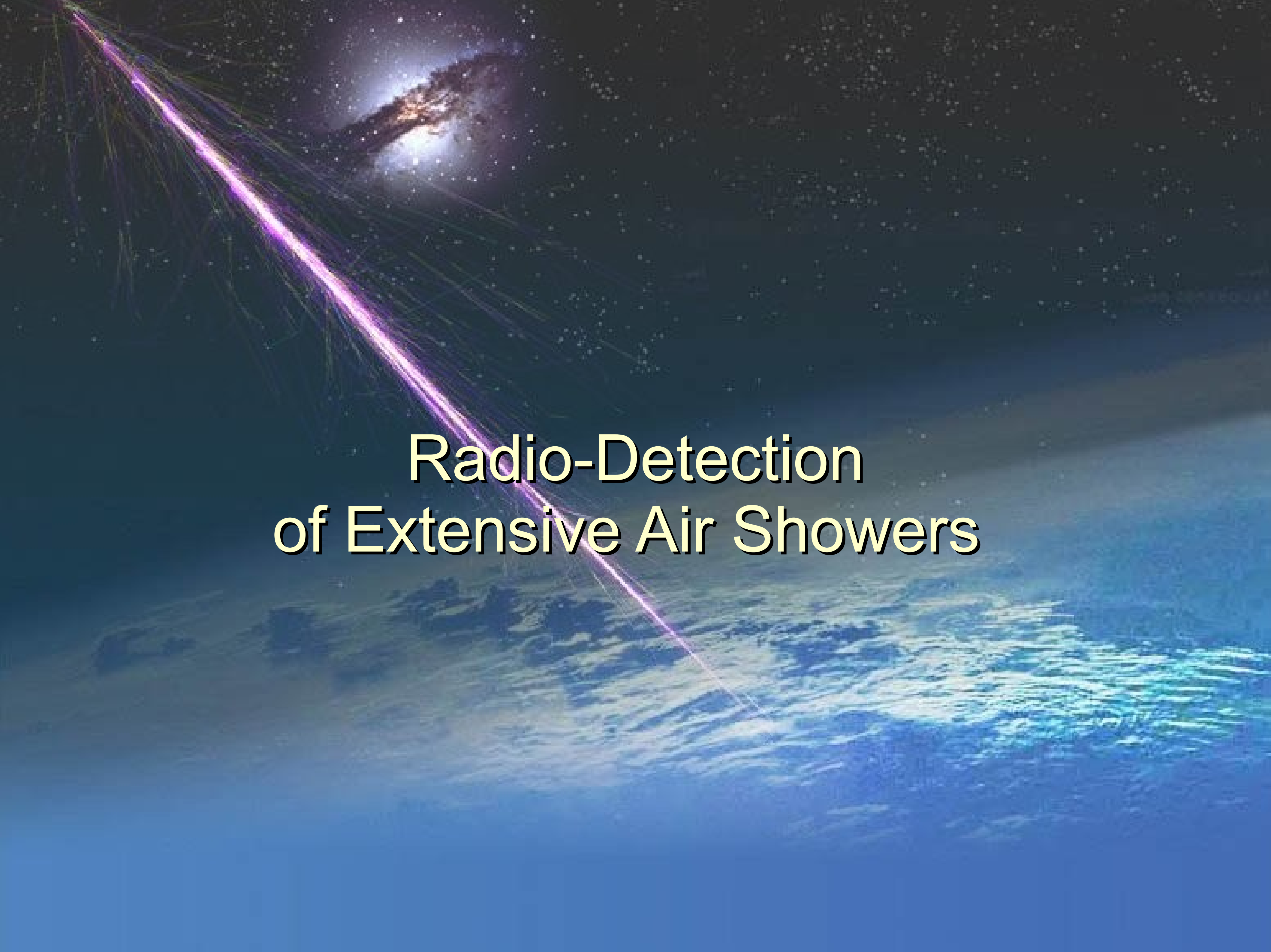
R. Thomas et al., J. Geophy. Res. 109, D14207 (2004)

Lightning Mapping Array @ Auger





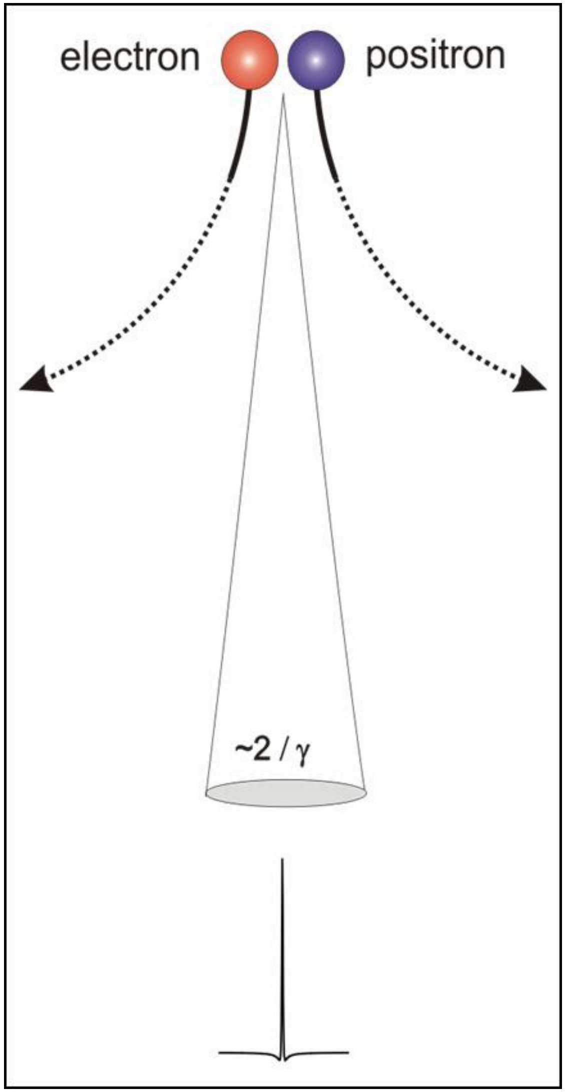
Brown et al., Eur. Phys. J. Plus (2012)



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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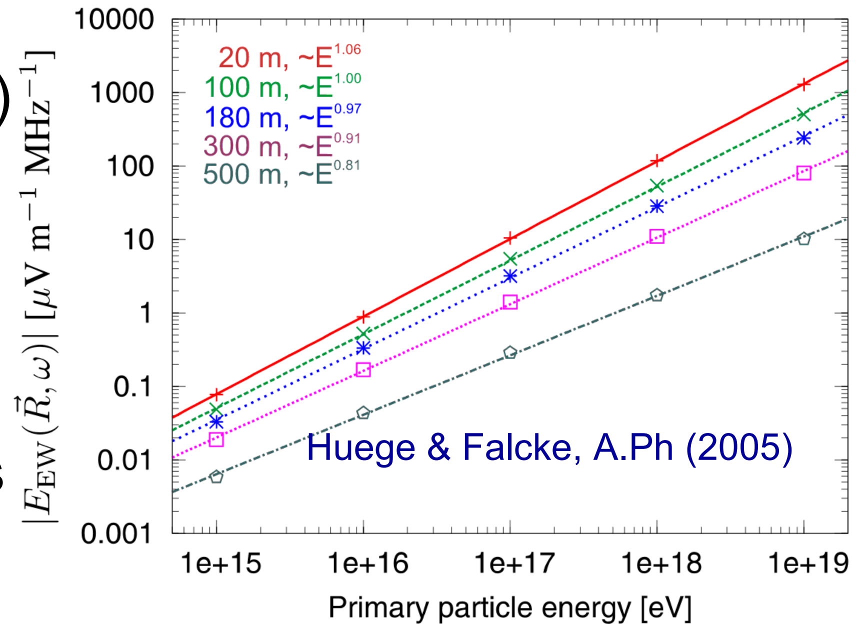
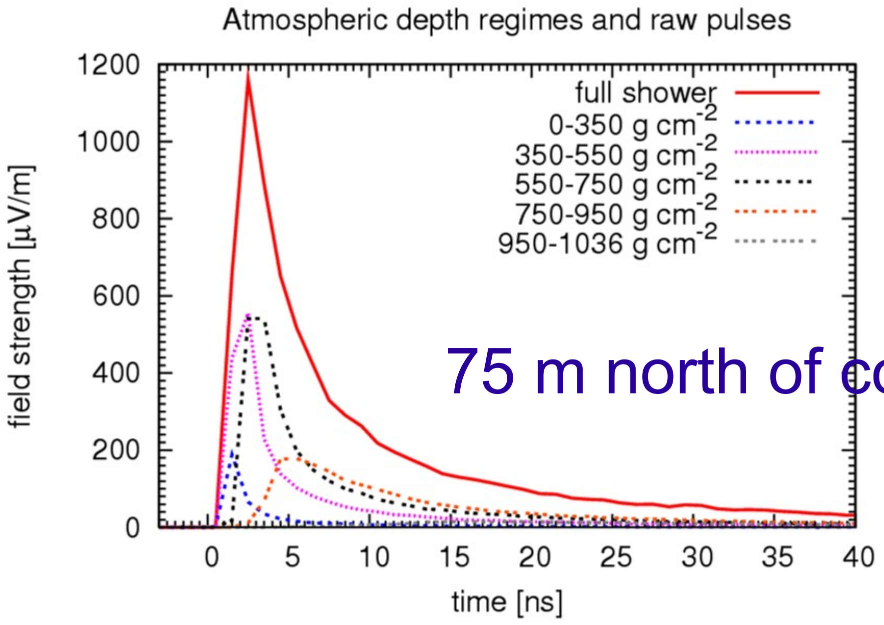
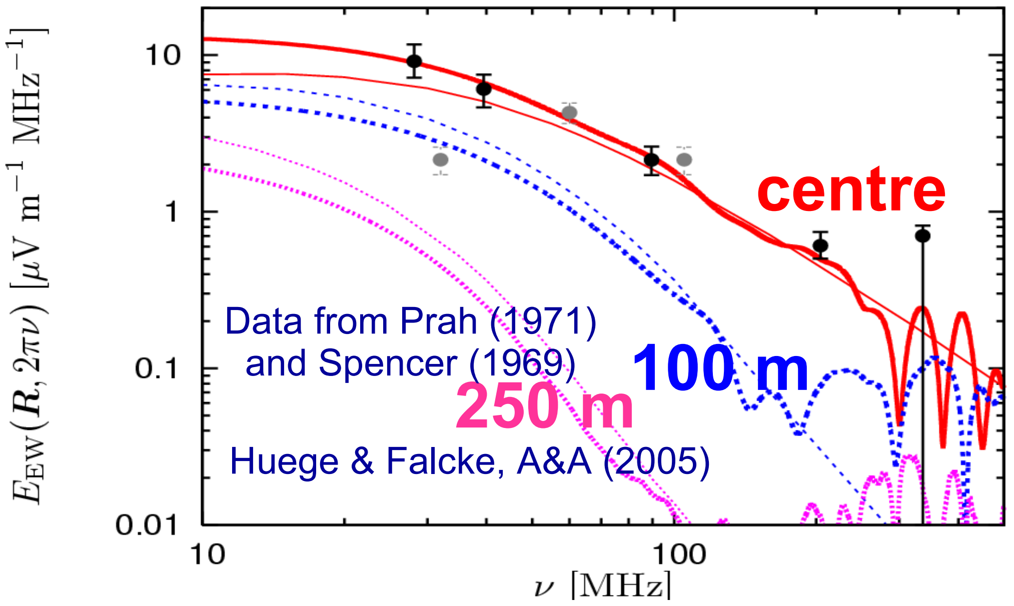






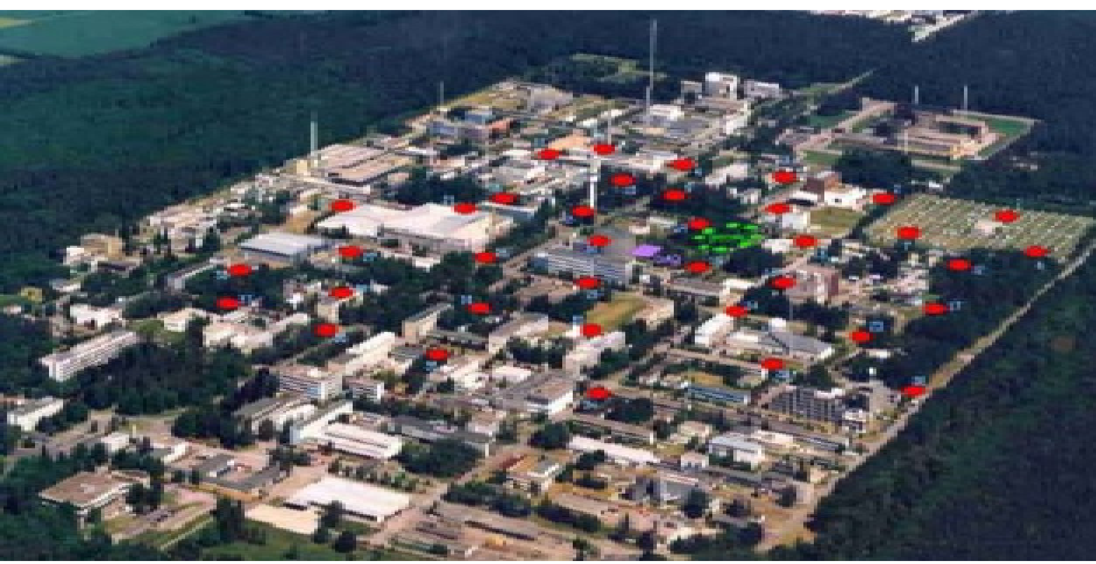
Renaissance of Radio Detection: Experiment

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.

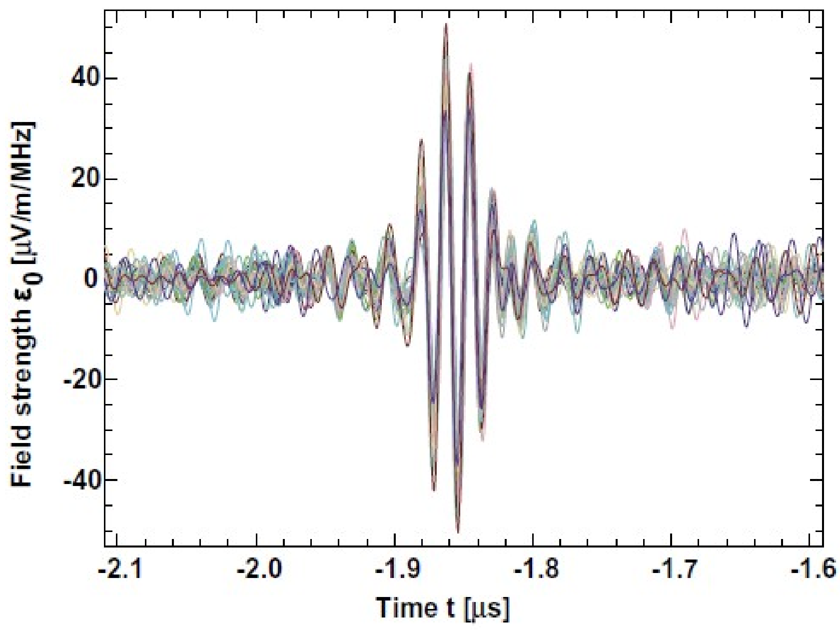
LOPES: Interferometric Reconstruction

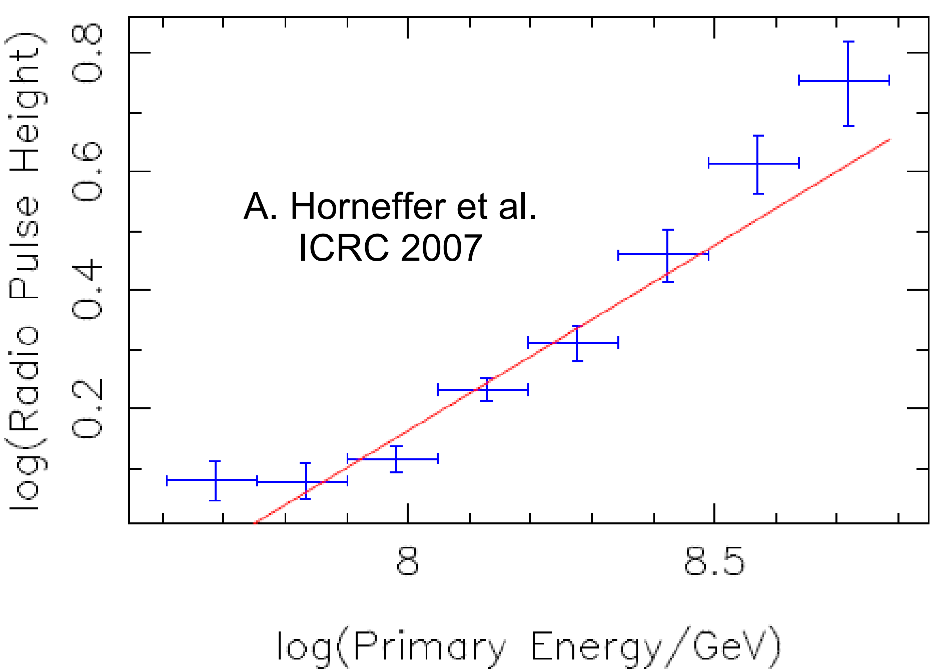
- Cross-correlated beam:

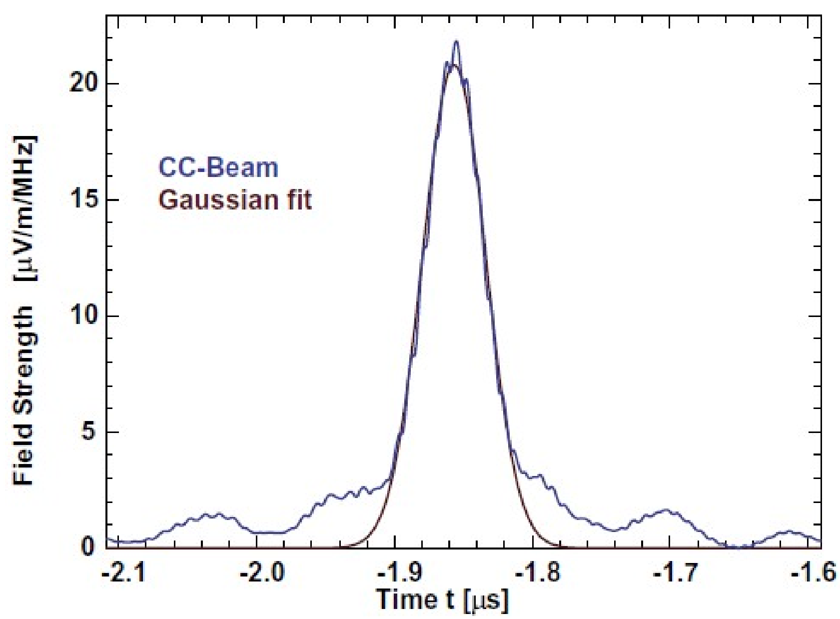
$$cc[t] = \pm\sqrt{\left|\frac{1}{N_{Pairs}}\sum_{i=1}^{N-1}\sum_{j>i}^{N} s_i[t]s_j[t]\right|}$$

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

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

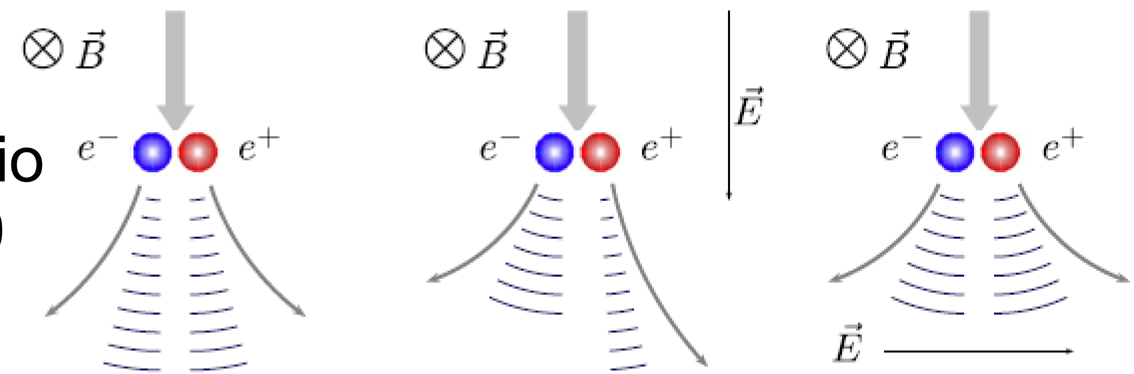




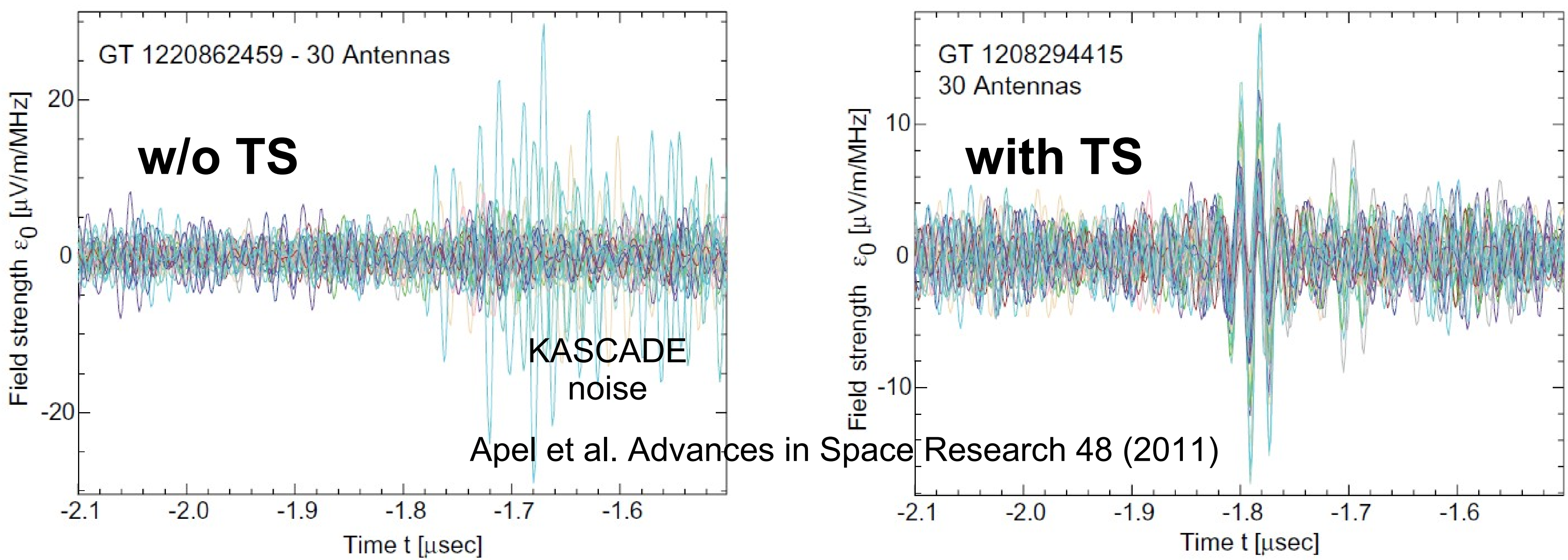


Thunderstorm effect on CR's radio signal

In presence of thunderstorm radio signal can be enhanced by x10



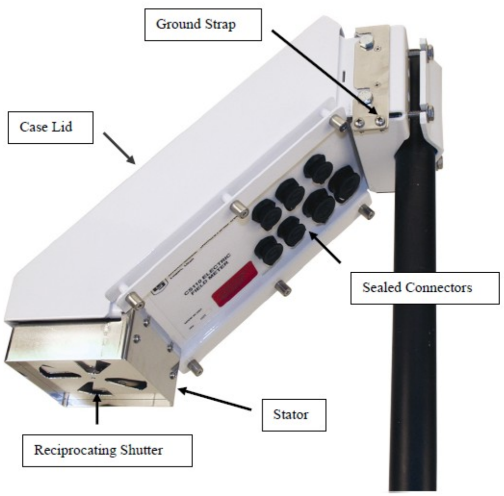
Buitink et al. (LOPES Collaboration)
A&A 467 (2007)

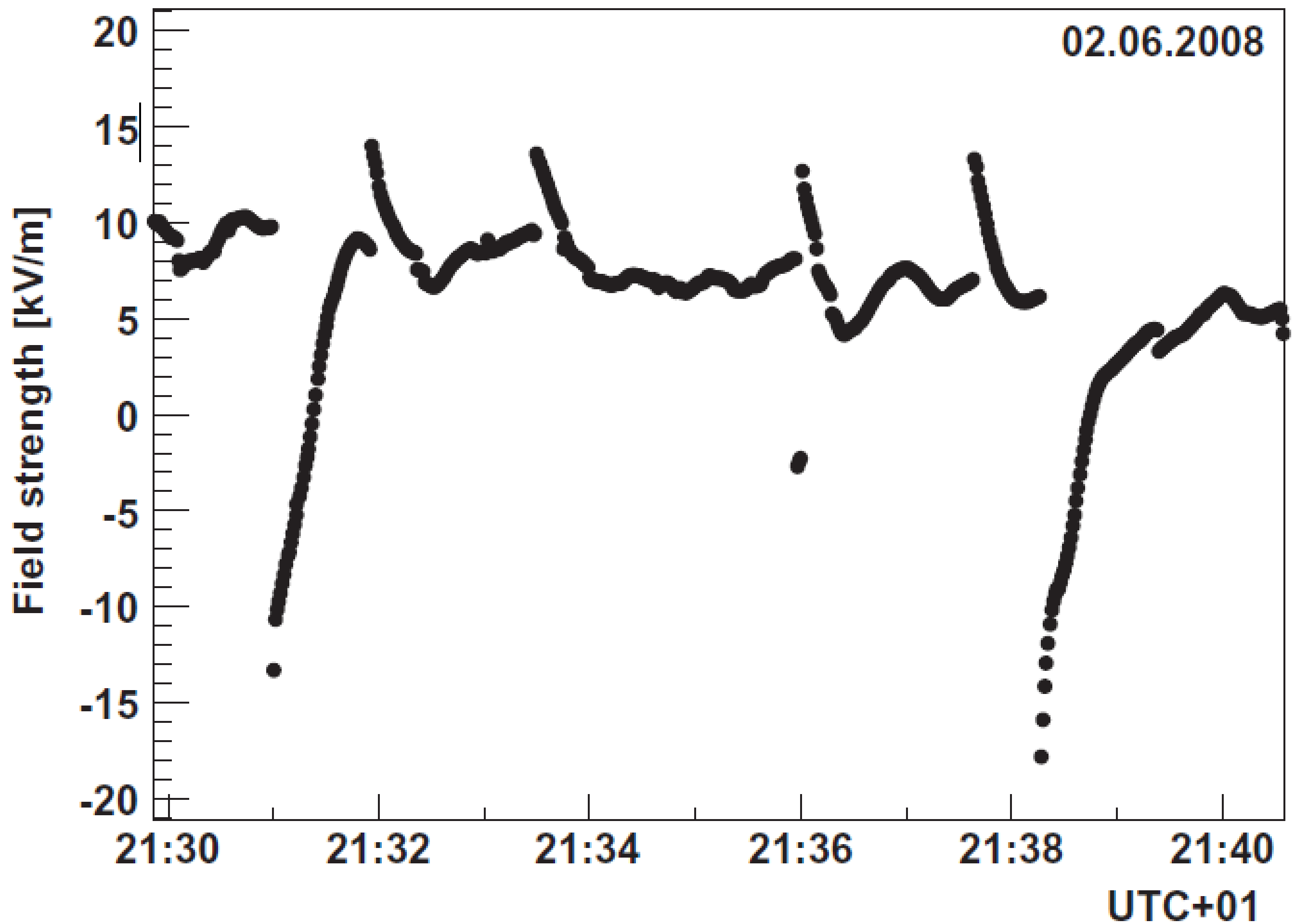


Apel et al. Advances in Space Research 48 (2011)

LOPES E-Fiels mill as Lightning detector

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

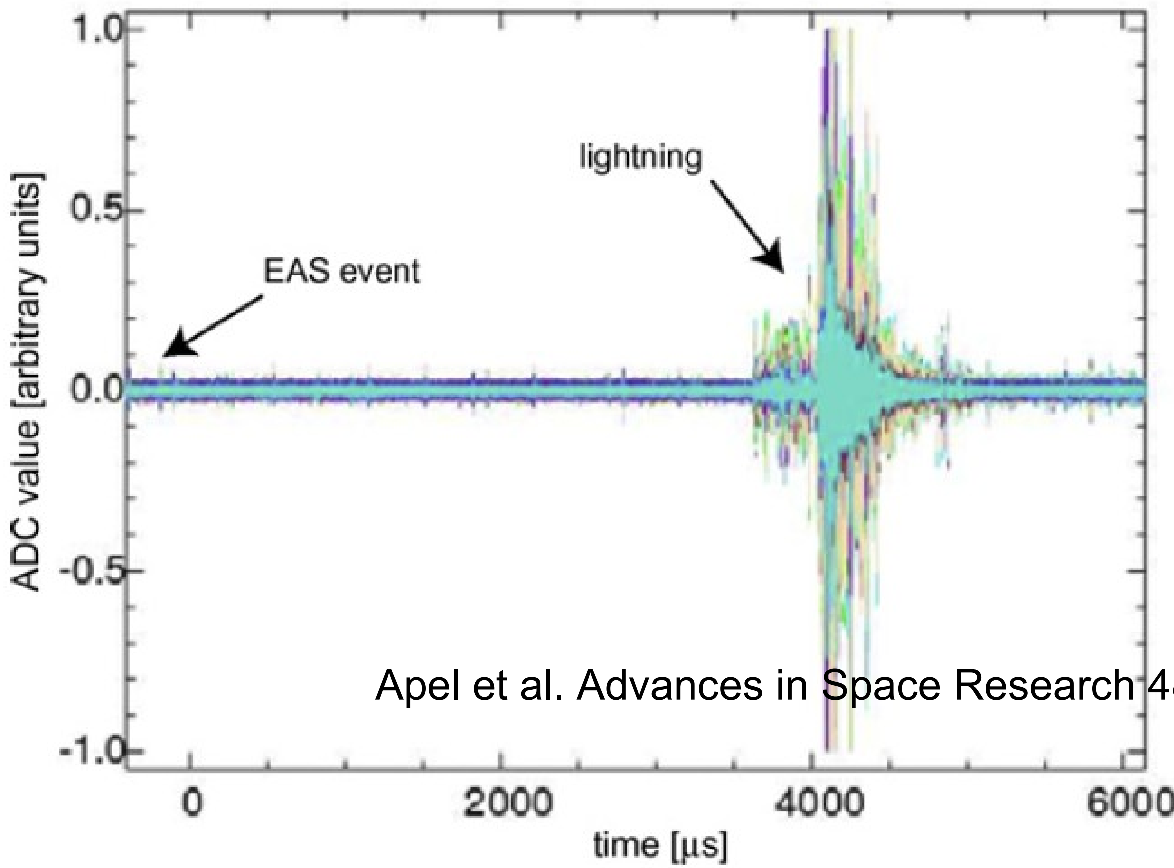


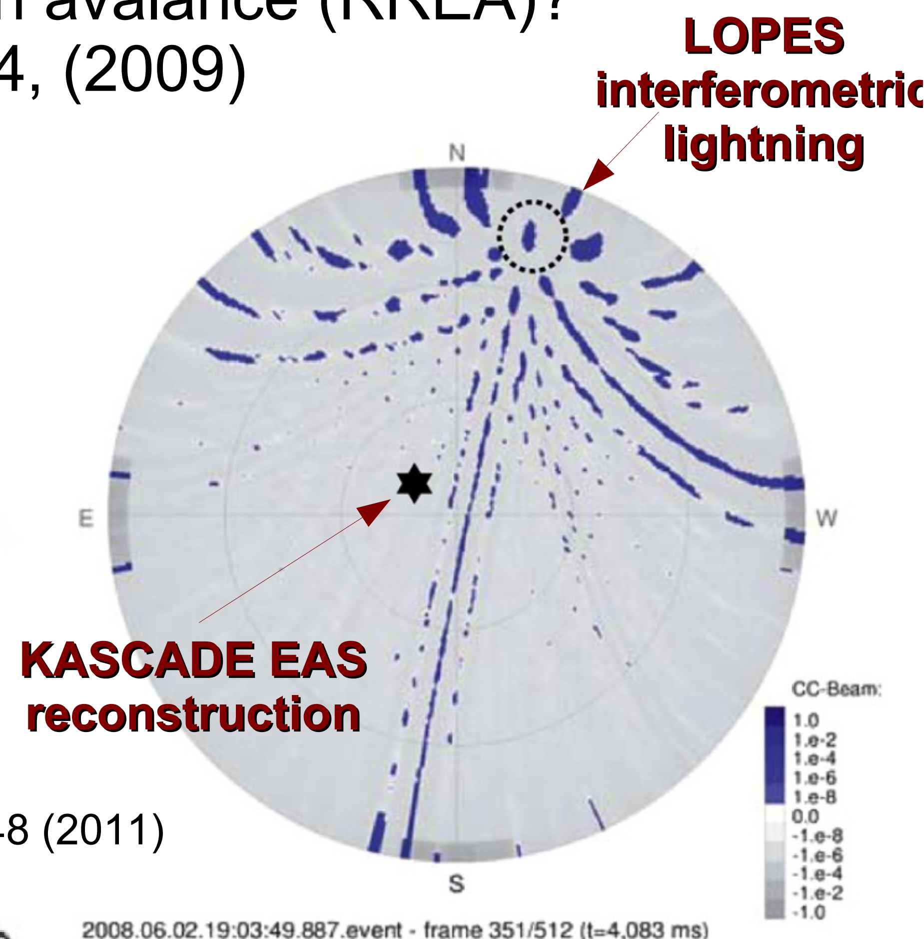


Apel et al. Advances in Space Research 48 (2011)

LOPES Lightning CR correlation with KASCADE

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

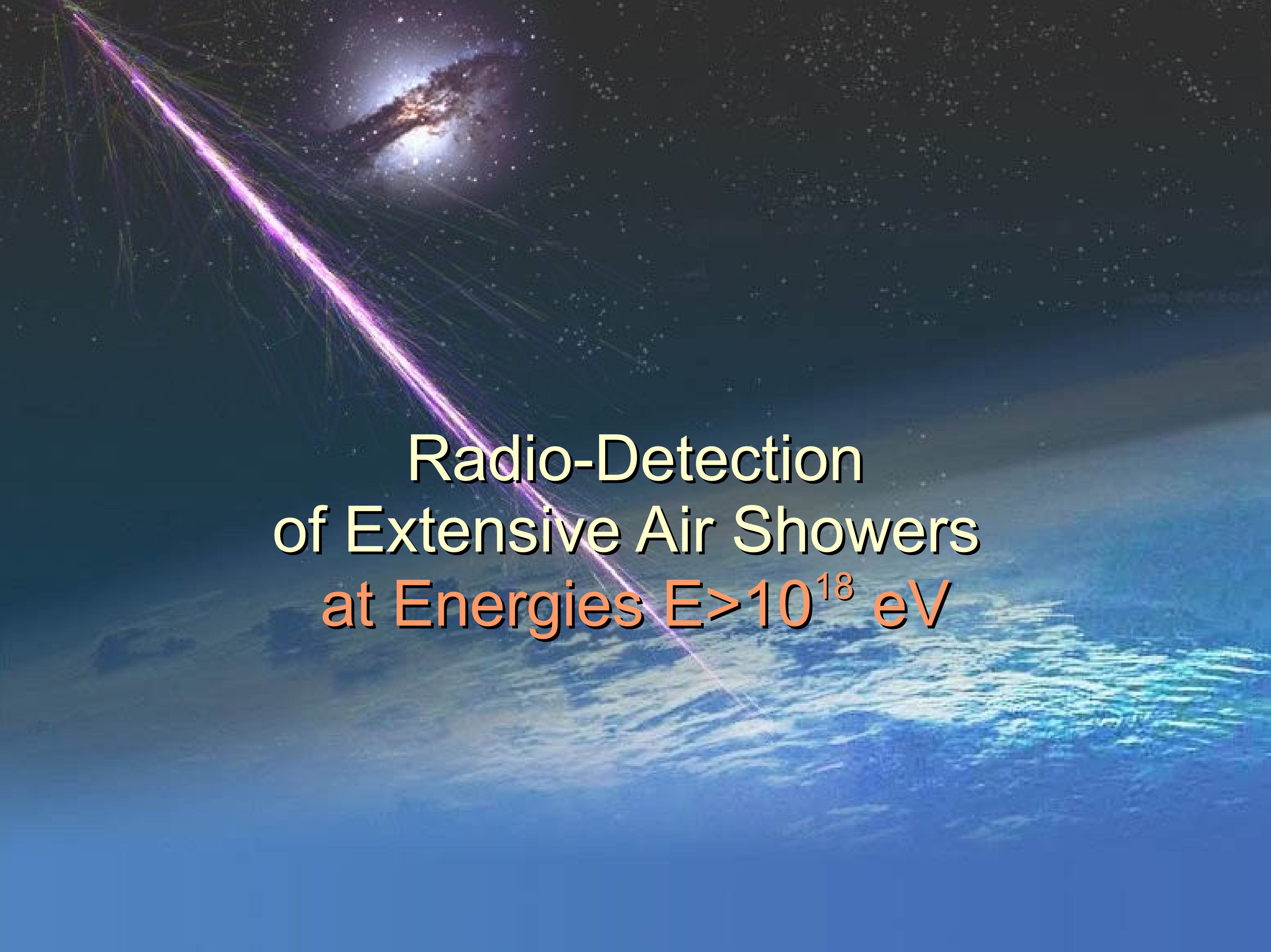




Apel et al. Advances in Space Research 48 (2011)

No significant correlation found

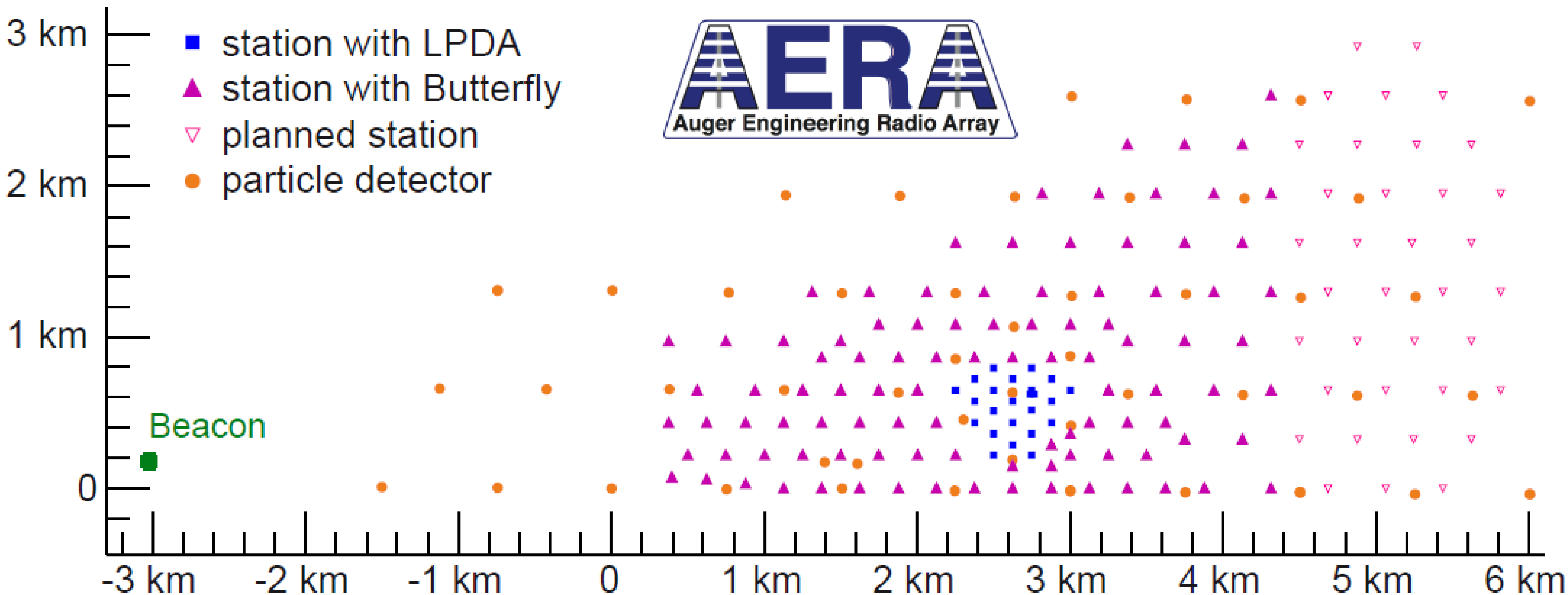
Similar RREA-pulse confirmed by Gurevich et al., Phys. Rev. Lett. 110 (2013)



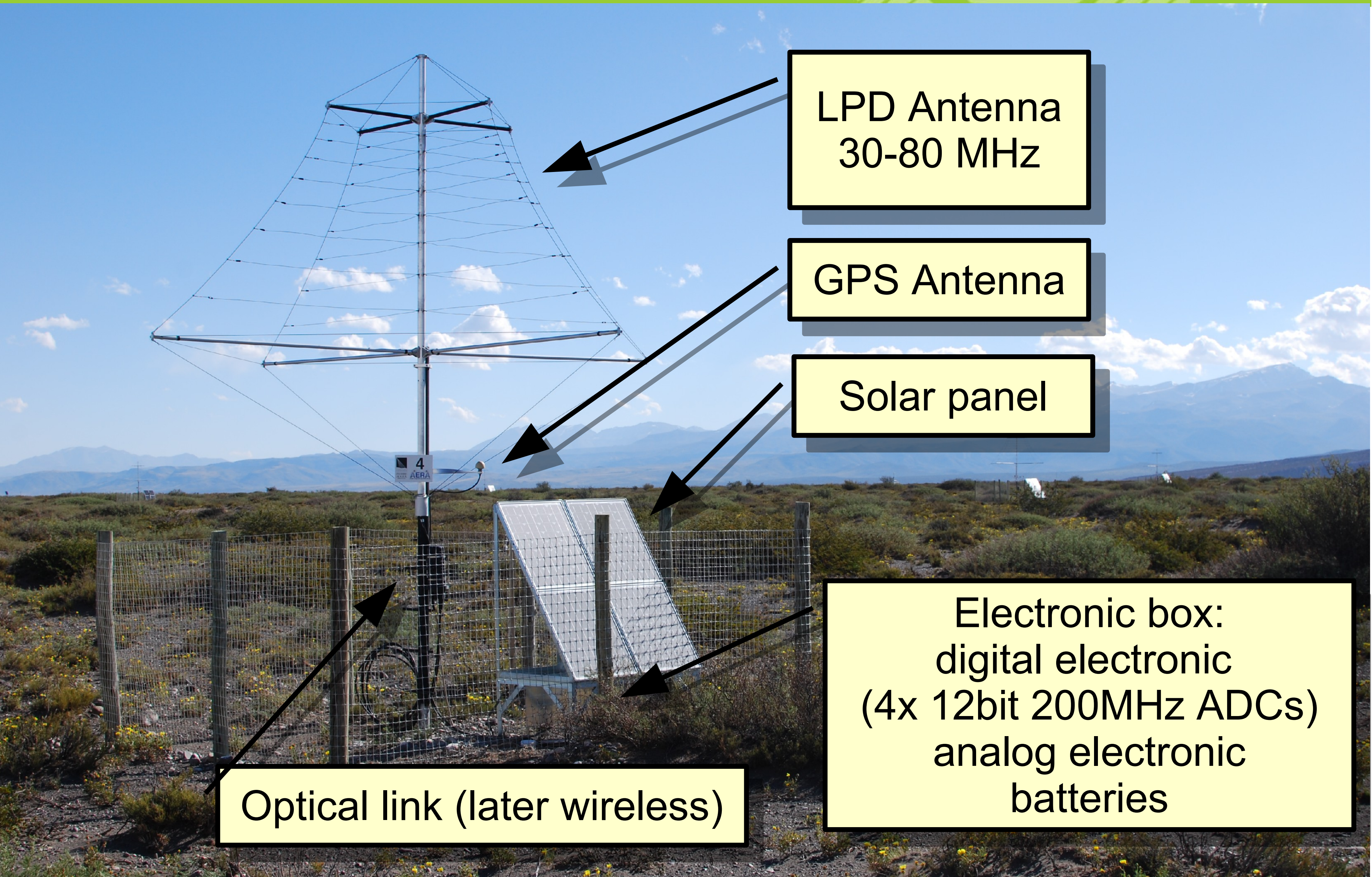
Radio-Detection of Extensive Air Showers at Energies $E>10^{18}$ eV

Radio EAS detection @ Auger

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

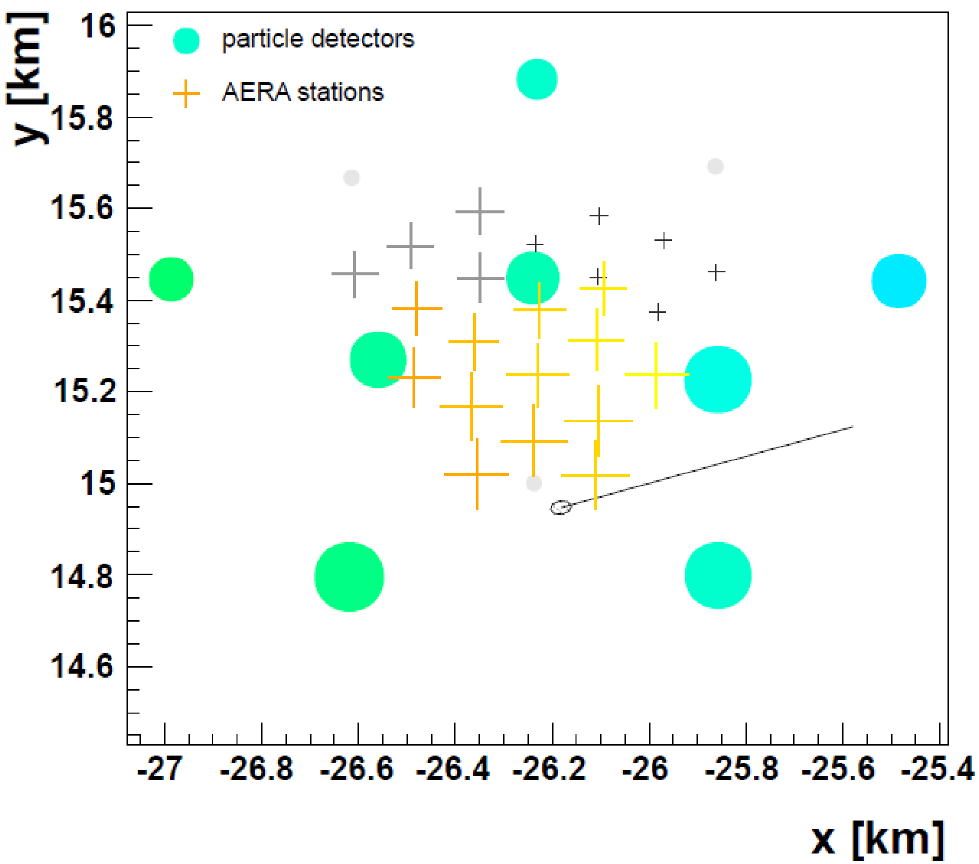


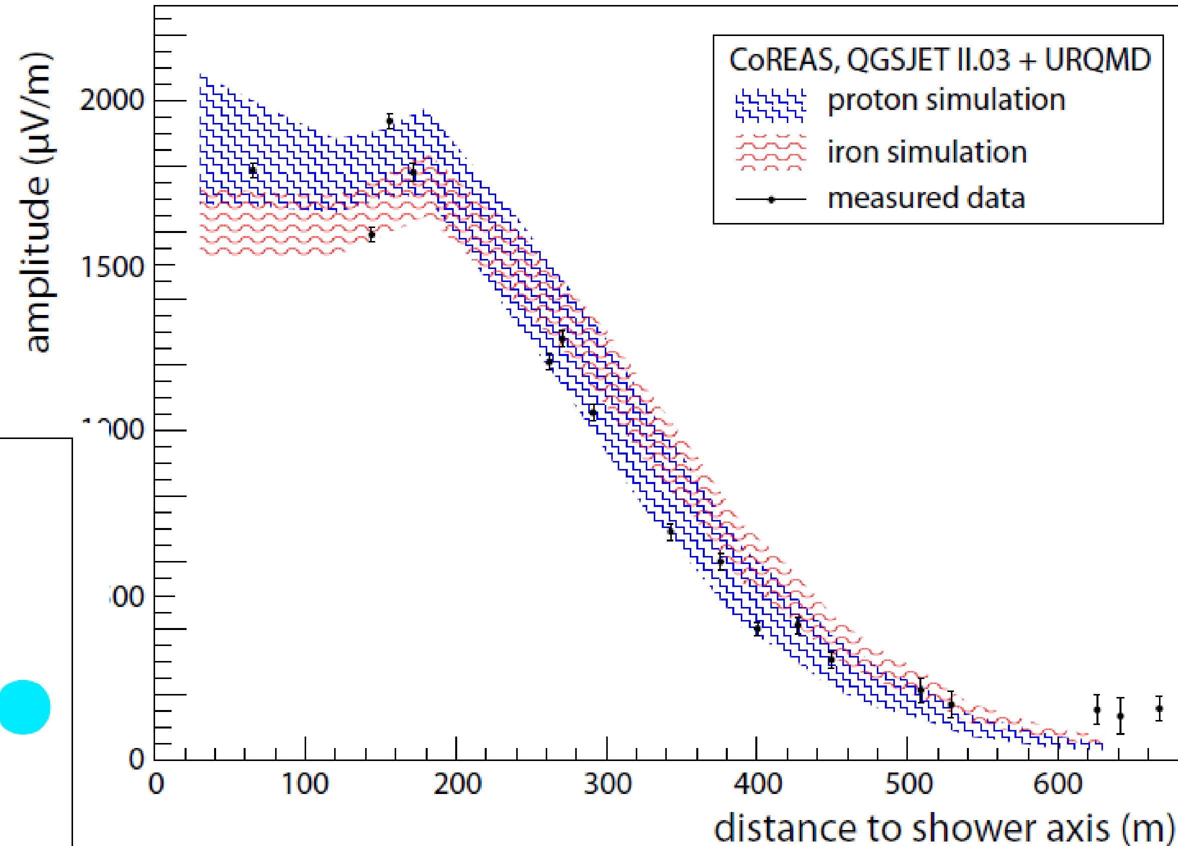
AERA Station



Radio EAS detection @ Auger

- Example event for AERA I
- Well described by simulations

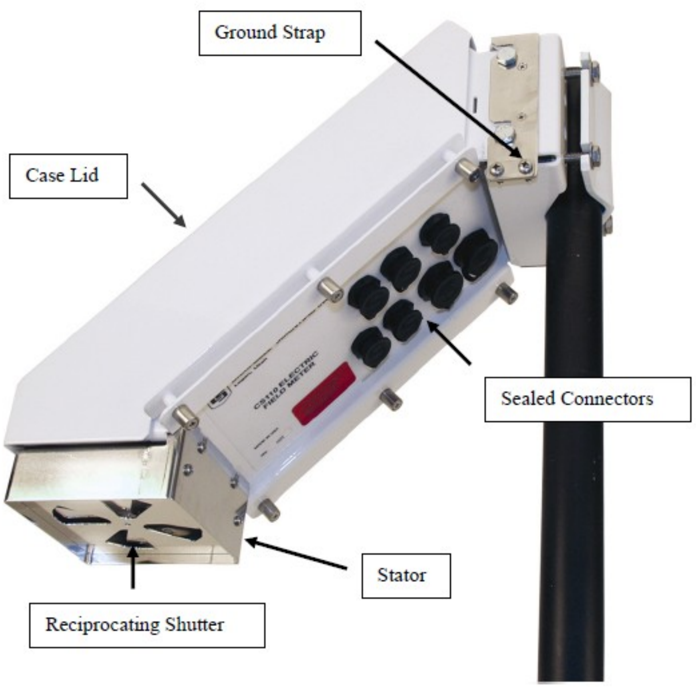


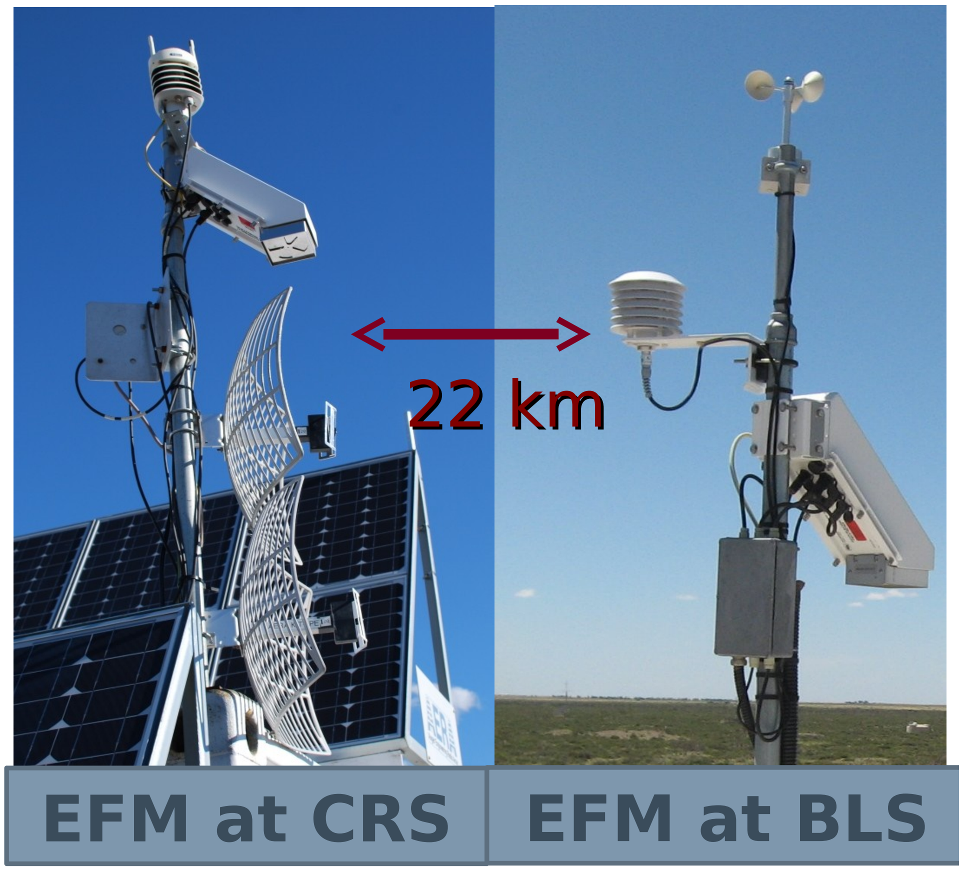


AERA
Auger Engineering Radio Array

AERA E-field thunderstorm detection

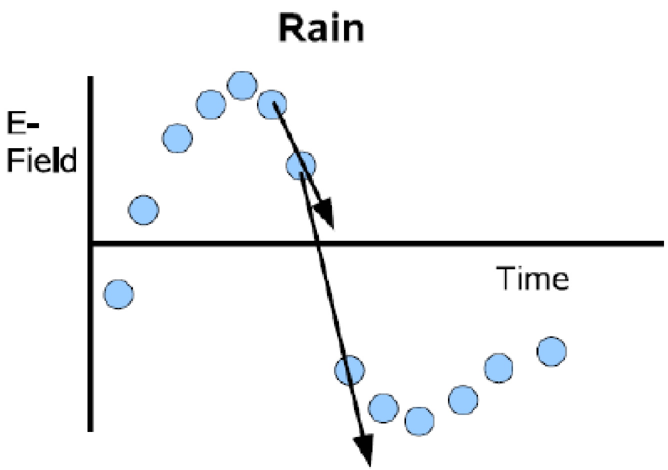
- E-Field mill (Campbell Scientific CS110)
- No spatial resolution
- 1 sec sampling
- 2 stations at Auger

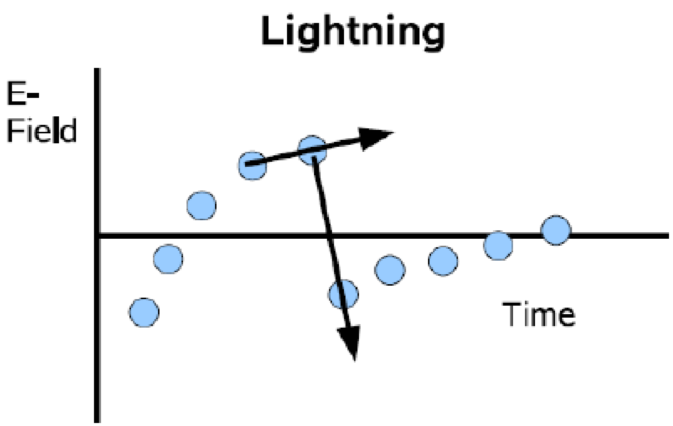




AERA E-field thunderstorm detection

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

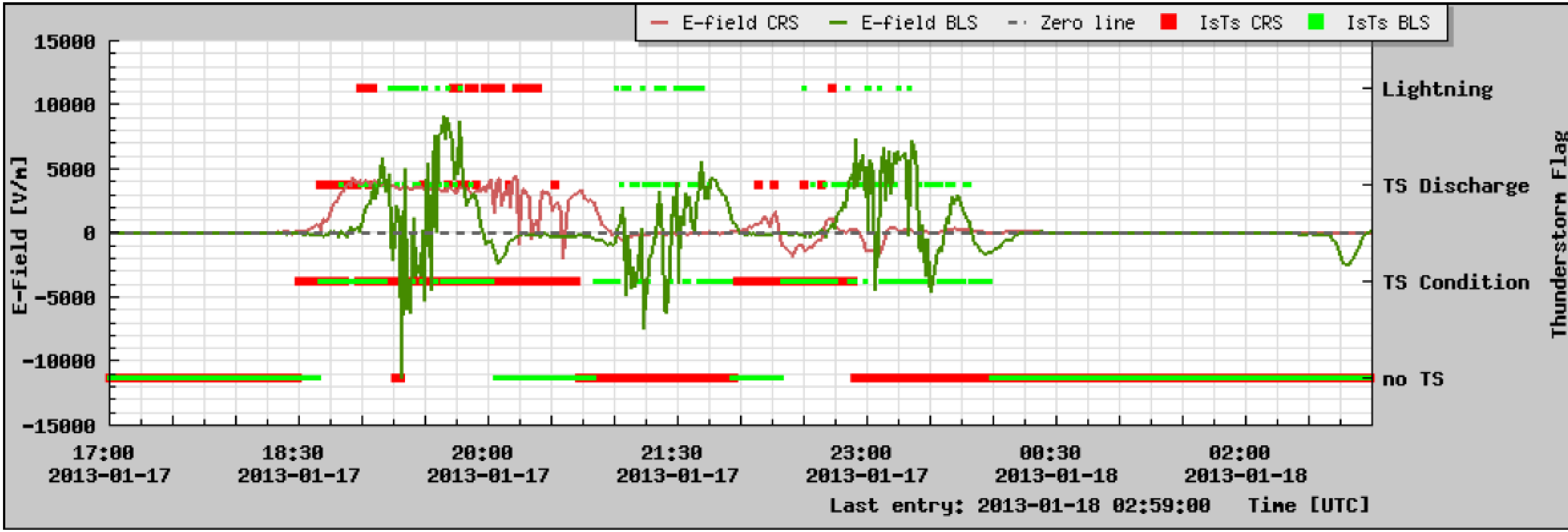




- 15 minutes around found event are marked as thunderstorm

AERA E-field thunderstorm detection

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

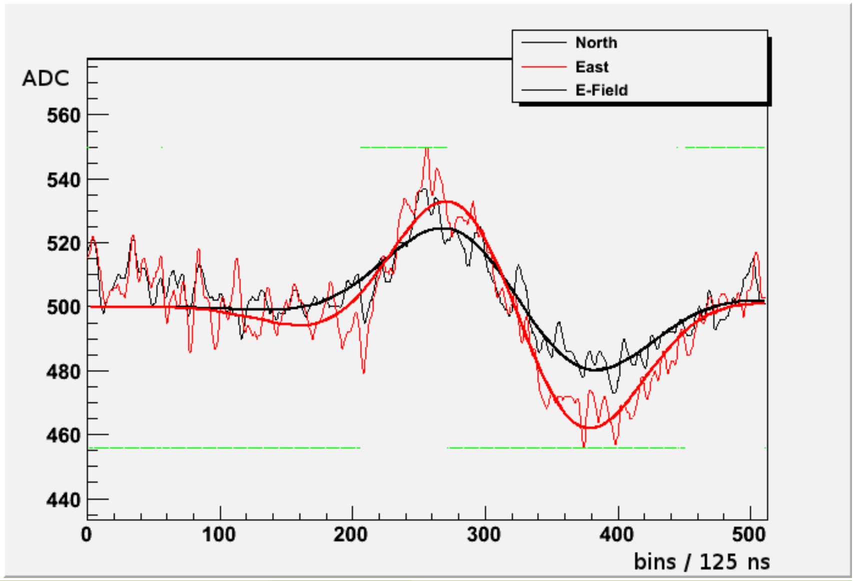


Lightning detection for AERA

Boltek StormTracker:

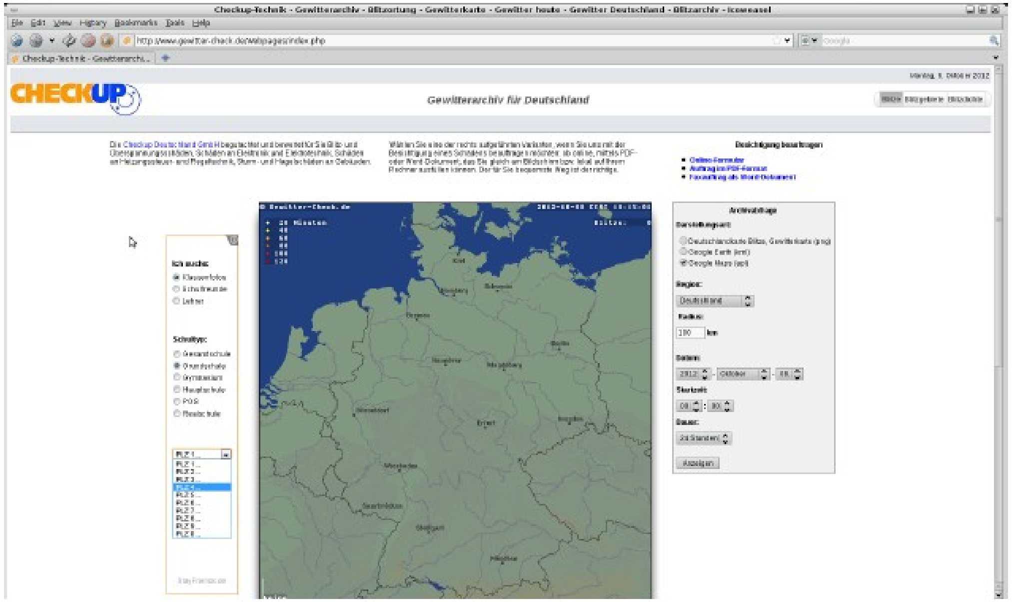
- Sensitive in kHz-region
- Semiprofessional system
- Lightning detection up to 500 km
- Roughly estimation of direction via fraction of N/S and E/W polarization
- Three systems installed in November 2012 in Argentina
- Time accuracy of PC

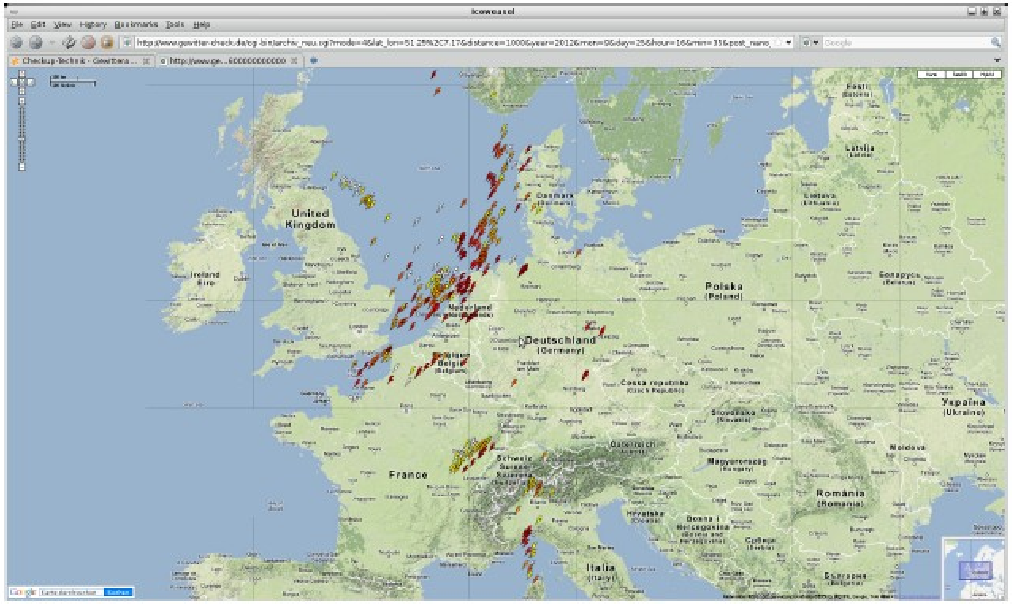
Uncertainty of order 10 ms
not enough for triggering
other detectors



CheckUp System (www.checkup-technik.de)

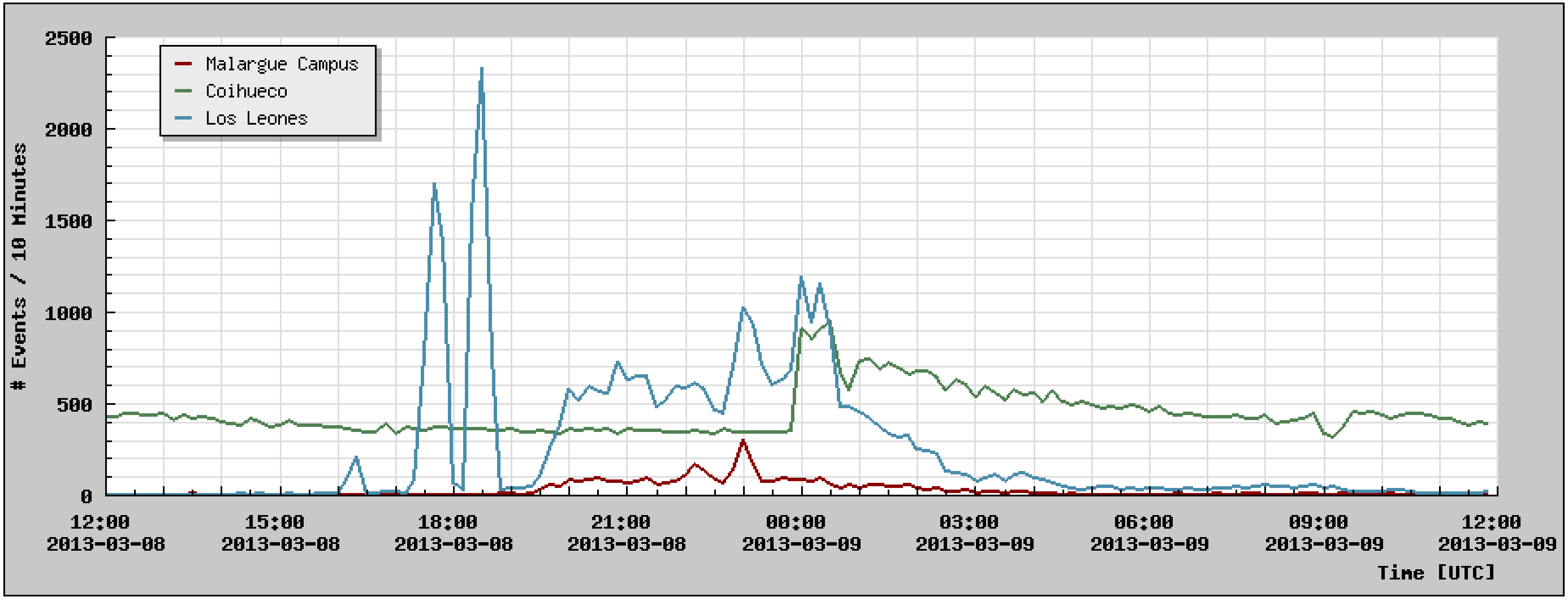
- 13 Boltek StormTracker with GPS-module in Germany
- Time of Arrival - Reconstruction
- ca. 100 m spacial resolution
- Webinterface delivers Google Earth data





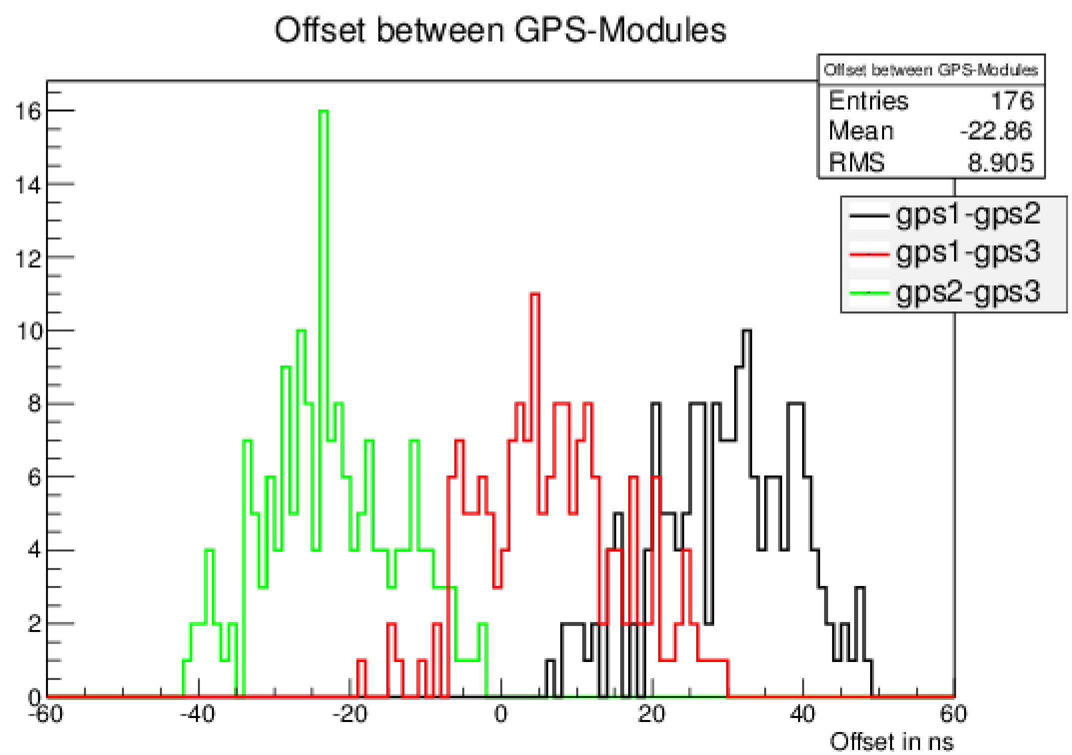
Lightning detection for AERA

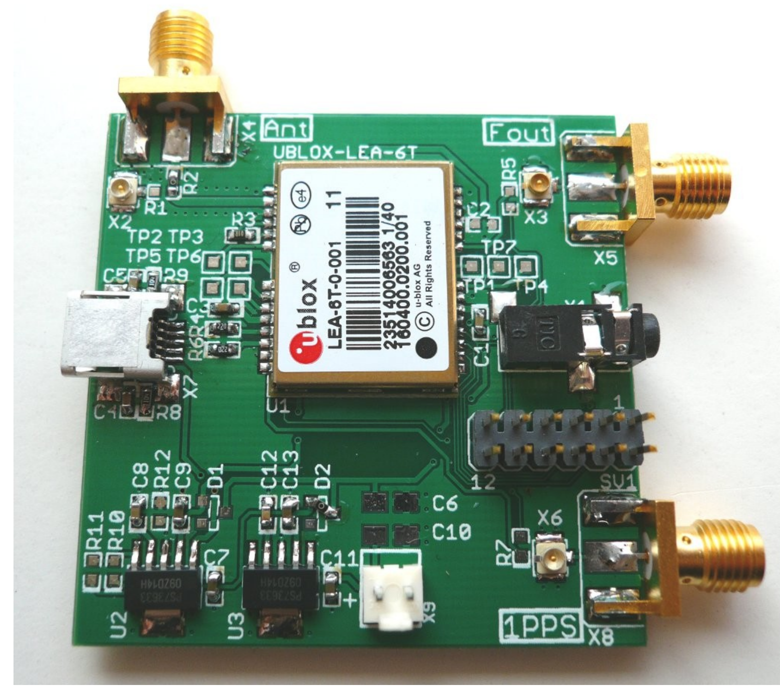
- Lightning data in Auger Mointoring available
- Clear signal e.g. for 9th of March 1:36 am elve



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



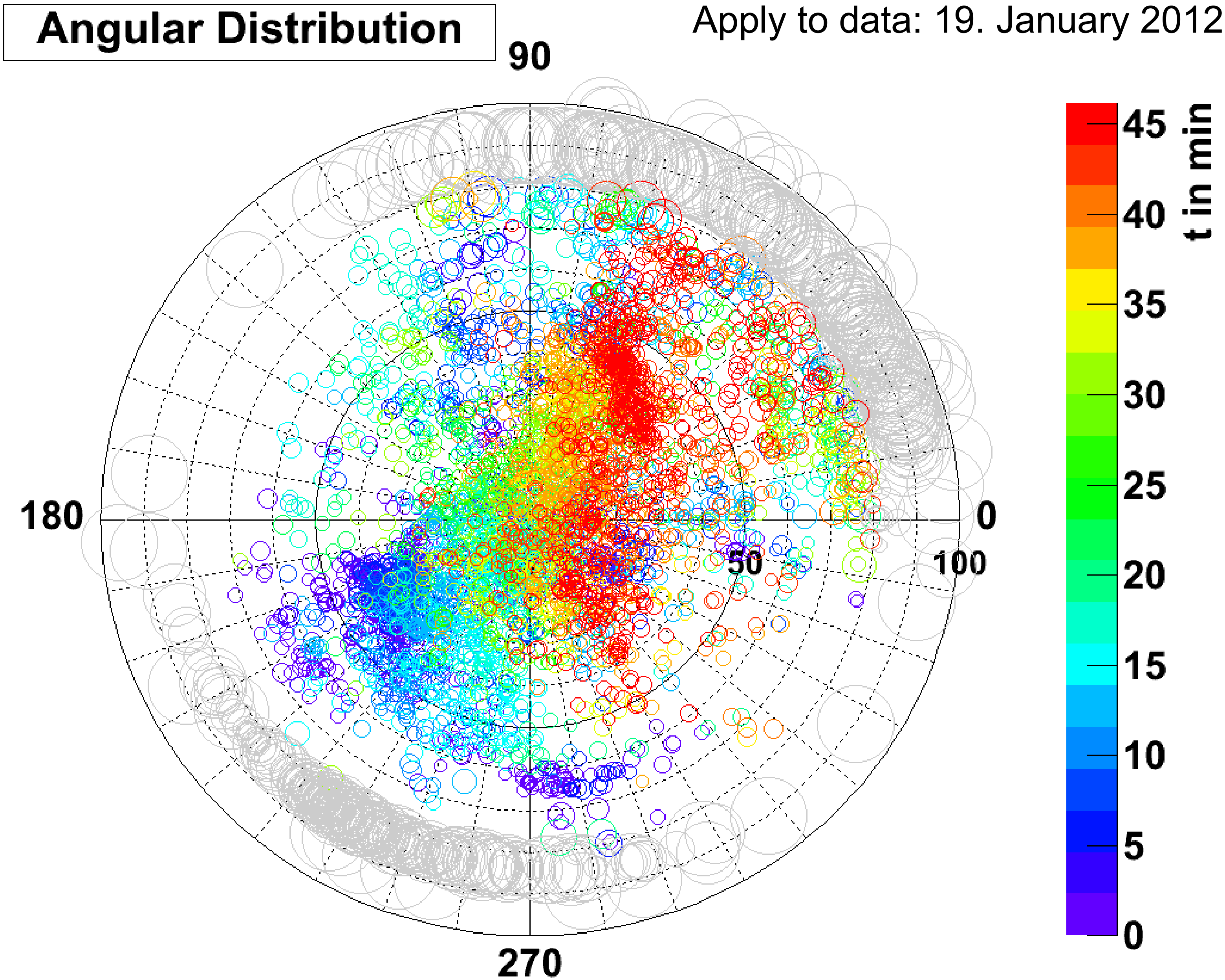


Lightning measuring with AERA

- 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

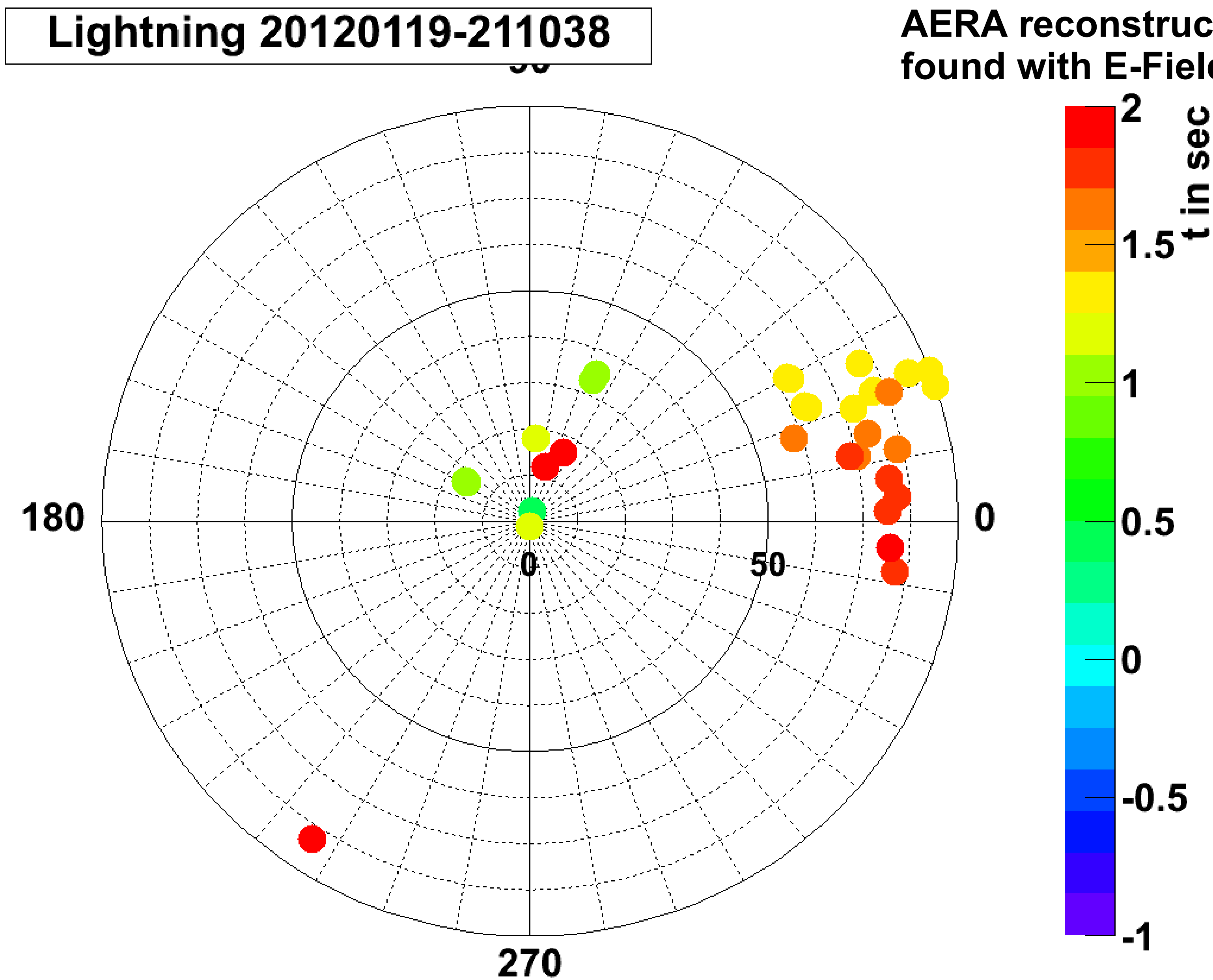
EFM triggered AERA Data

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 in Auger with:

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

Correlation difficult because needs

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