Thunderstorm Observations with LOPES

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Radio Detection of Extensive Air Showers

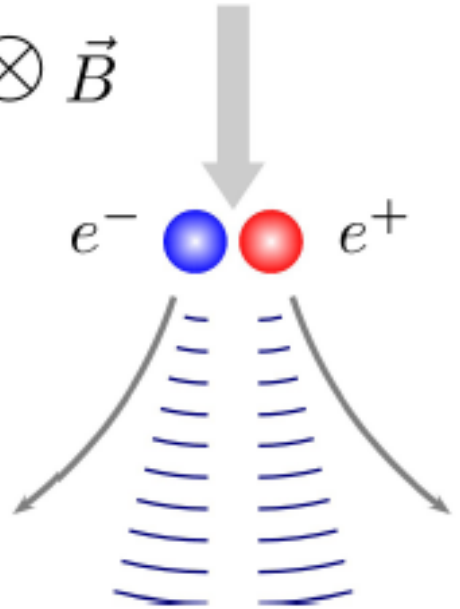
- Source of the radio emission is the electromagnetic component
- Radio detection complementary to particle detection of EAS
- Emission dominated by geomagnetic effects

  ➔ geosynchrotron emission

=

- deviation of electrons and positrons

  in the geomagnetic field
- Synchrotron emission
- Coherent signal up to c. 100 MHz
- Short (ns) pulse



Radio Detection of Extensive Air Showers

= New detection technique of high-energy cosmic rays!

- **Calorimetric measurement**

  ➔ primary energy

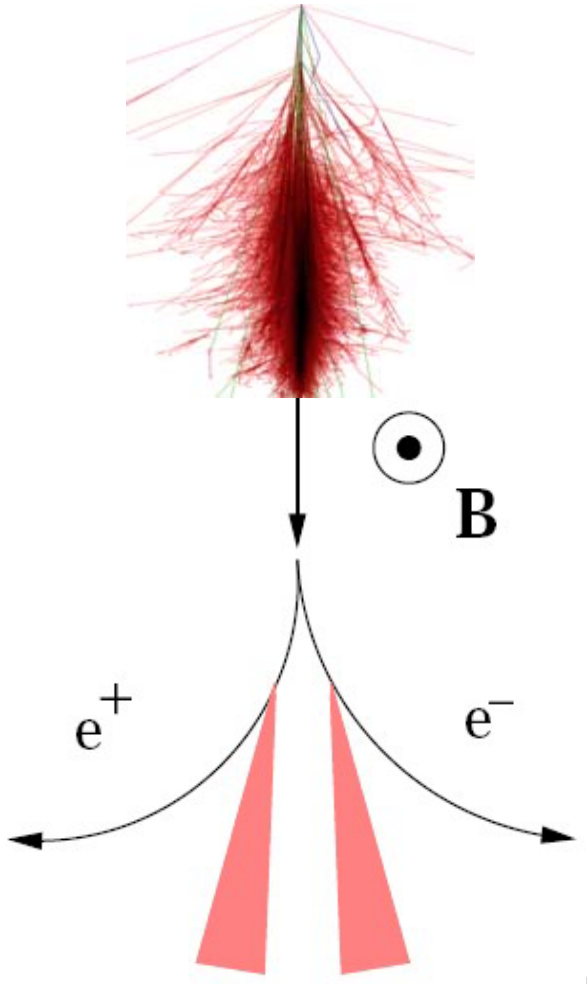
- **Access to longitudinal development**

  ➔ mass estimation?

- **Interferometry possible**

  ➔ excellent direction resolution

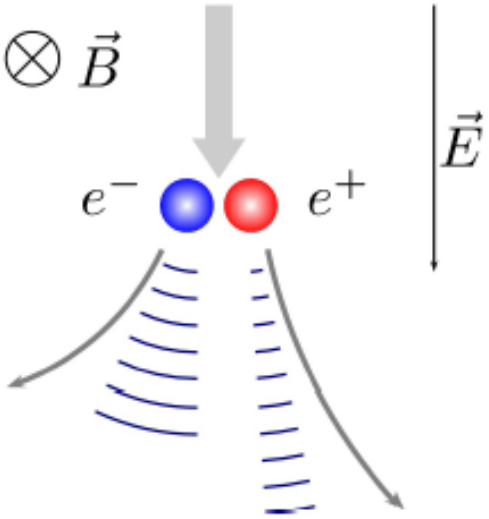
- **(nearly) 100% duty cycle**

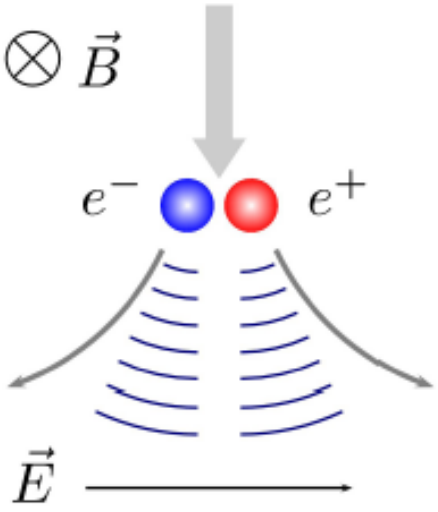


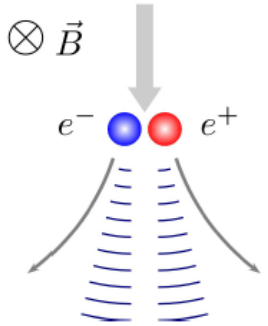
➔ LOPES, CODALEMA, AERA, ….

➔ Talk on Friday by Daniel Huber

Influence of Additional Electric Fields

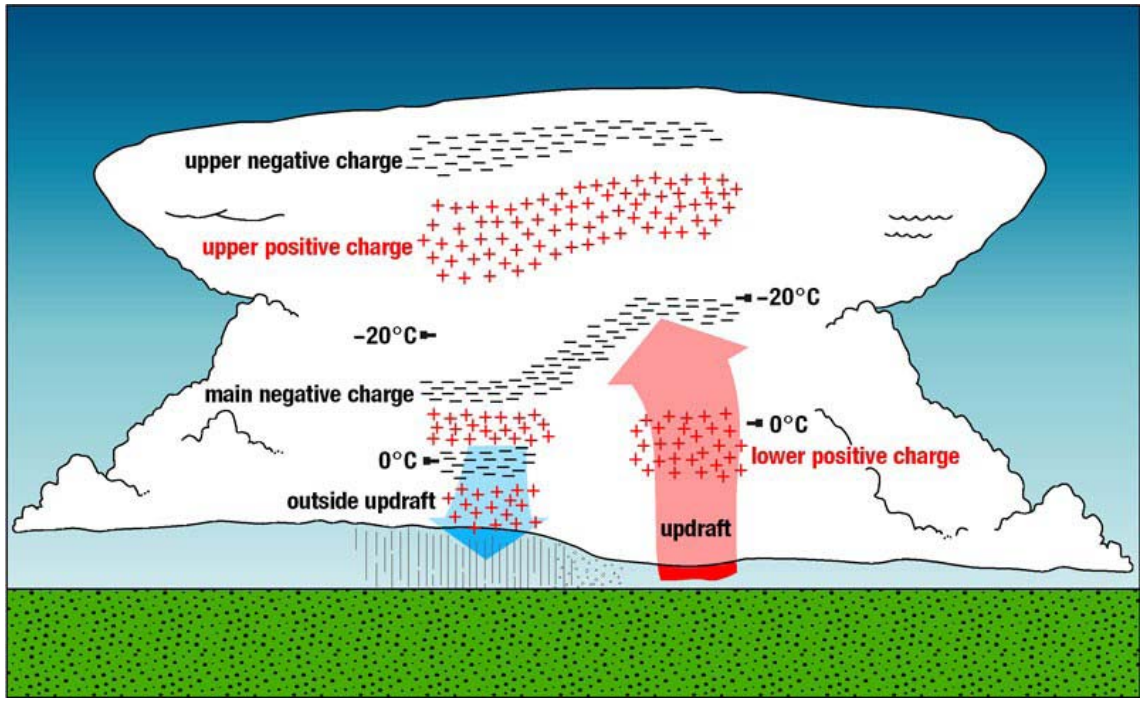






➔ **Monitoring necessary in Radio-EAS-Experiments**

Thunderstorm clouds: large electric fields



- **Normal weather**
- -100 bis -200 V/m stable

- **Thunderstorm**
- At ground up to 20 000 V/m
- In clouds up to 100 kV/m
- Jumps at discharges

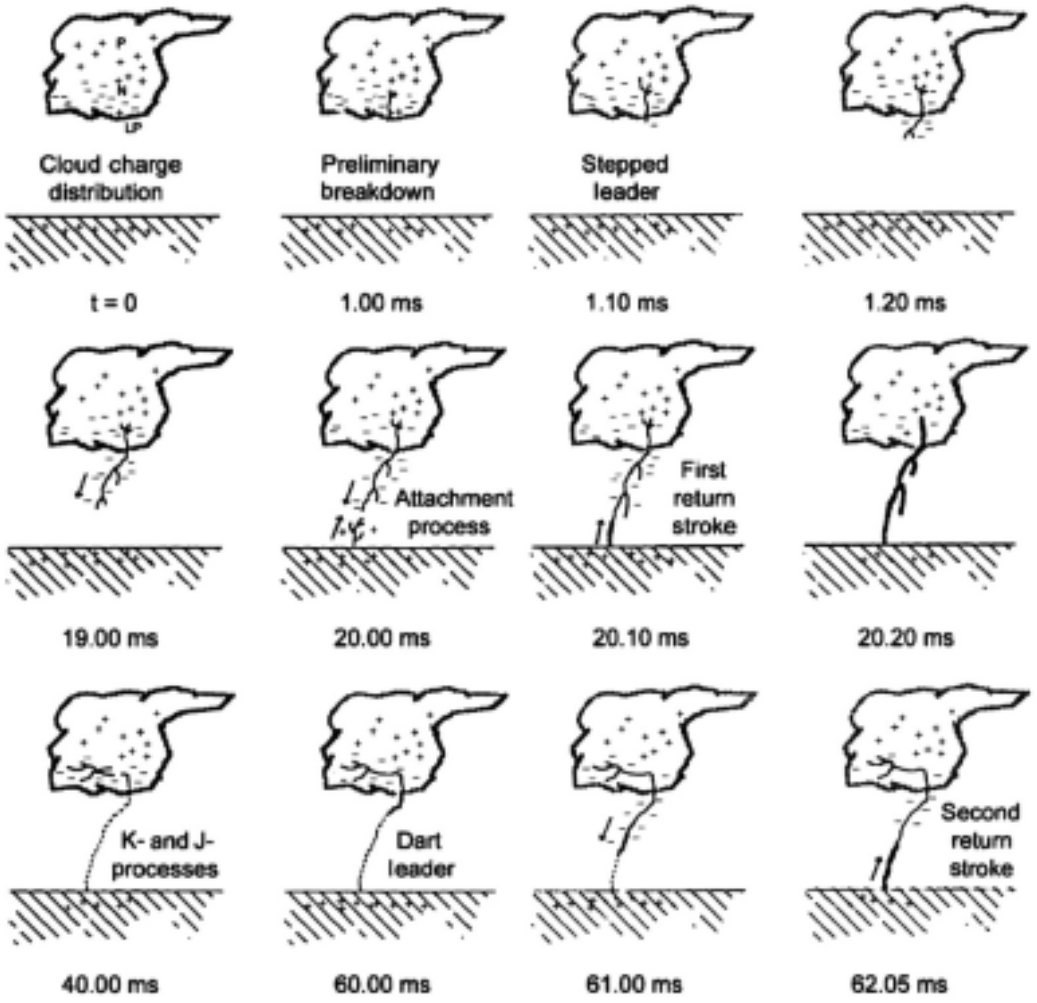
➔ **A number of different discharge mechanisms can lead to different disturbances of the radio signal!**

➔ **Additional radiation by acceleration of ionized electrons within clouds**

Atmospheric discharges

➔**Stepwise development of a lightning**

➔**Up to hundreds of milliseconds!**



Relativistic Runaway Breakdowns (RBB)

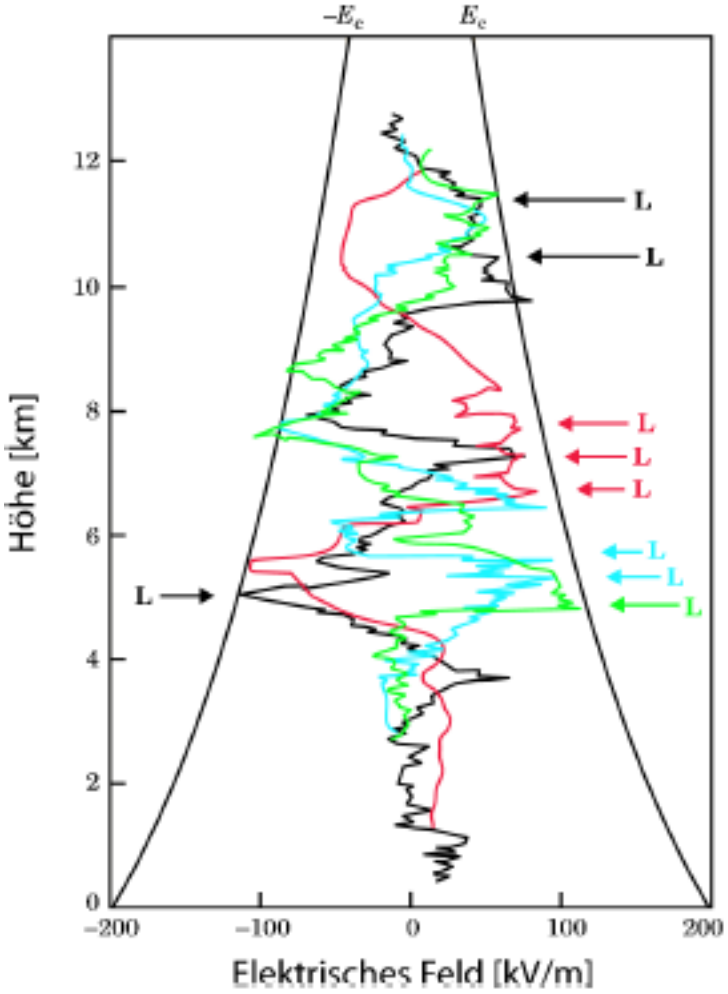
➔Avalanche breakthroughs by large electric fields!

➔Ionisation losses are smaller than energy gain in electric fields ➔ electron energy increases (~100MeV) ➔ electrons again seed electrons ➔ avalanche

➔ stepped leader (plot 3, last slide) could be RBB

➔ start of RBB (seed electrons) could be provided by EAS shower maximum

➔ **theory: EAS provide seed electrons for RBB and each lightning need as initiation a RBB!! (not proved)!**



Balloon measurements in a thundercloud
L= lightning!

Lightning = phenomenon still not fully understood

- **Main problem: How lightnings are initiated?**
  - Di-elektric breakthrough of the atmosphere?

    Problem: electric fields too small for classical breakthrough.

  - Initated by high-energy cosmic particles?

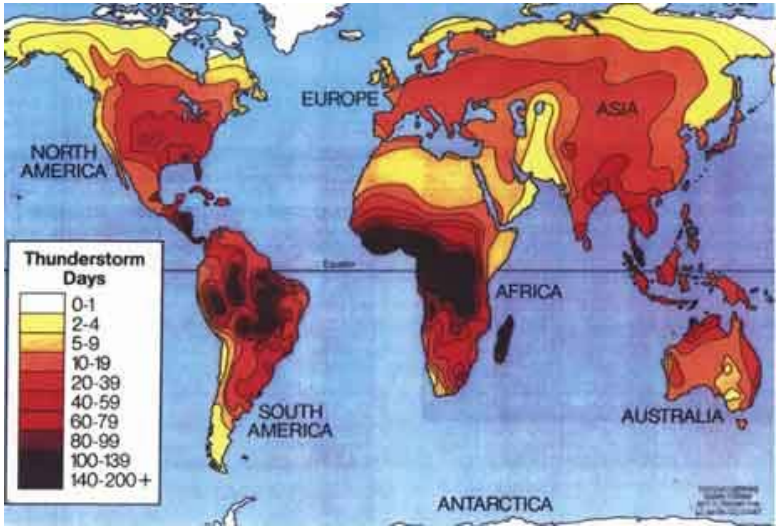
    or better: large densities of electromagnetic particles in a strong E-field in thunderstorm clouds?

➔ **Optical lightning observations**

➔ **Observations of E-fields**

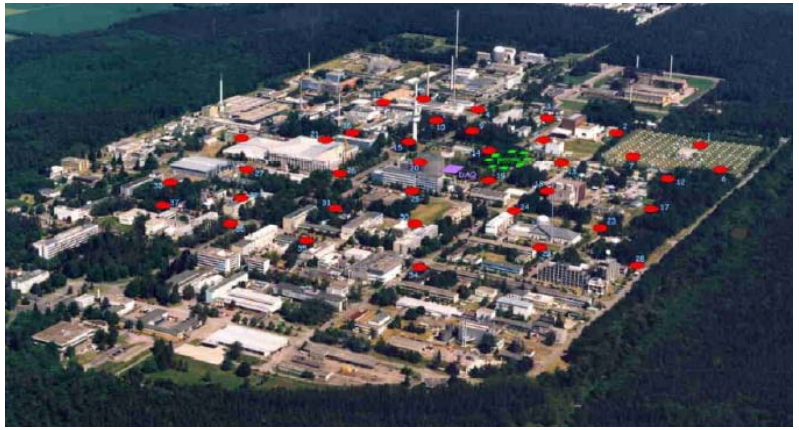
➔ **Observations in radio**

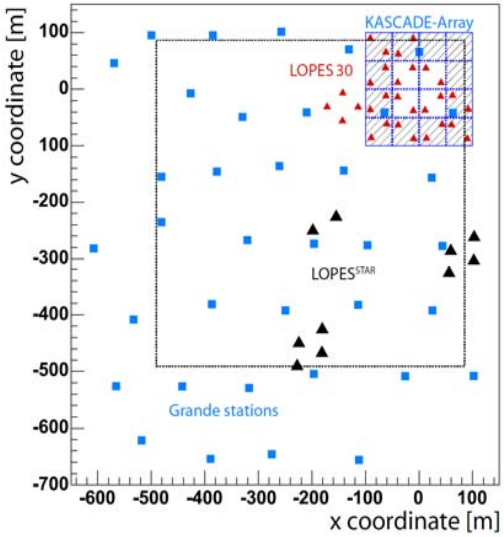
Contrary to optical studies, with radio one can look into the clouds!



World distribution of lightning

The LOPES Experiment





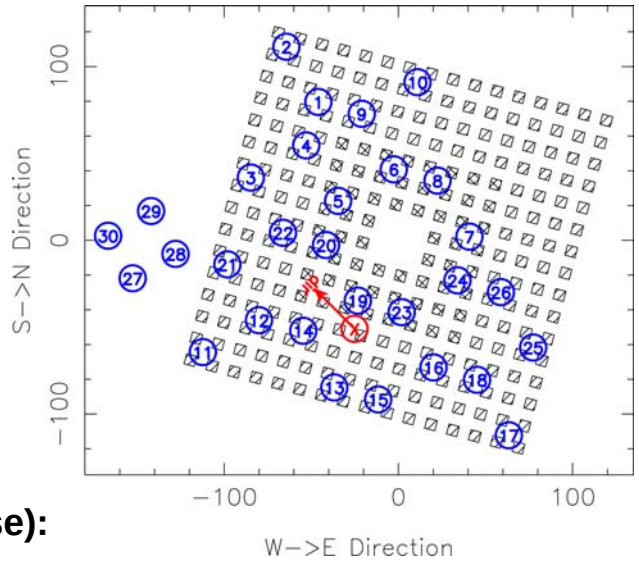
- **Dipol antennas at calibrated EAS experiment KASCADE-Grande**
- **Study of the radio emission and all correlations with shower observables**
- **Theory und simulation of the radio emission**
- **Improvements and optimization of hard- and software for large-scale application**

LOPES 30 Event Example

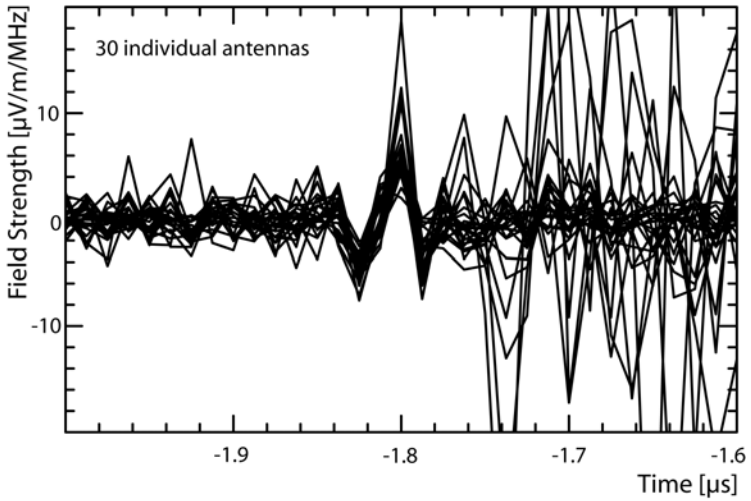
-radio reconstruction inclusive calibration factors of antennas
➔CC-beam value (per event)
➔Field strength (per antenna)

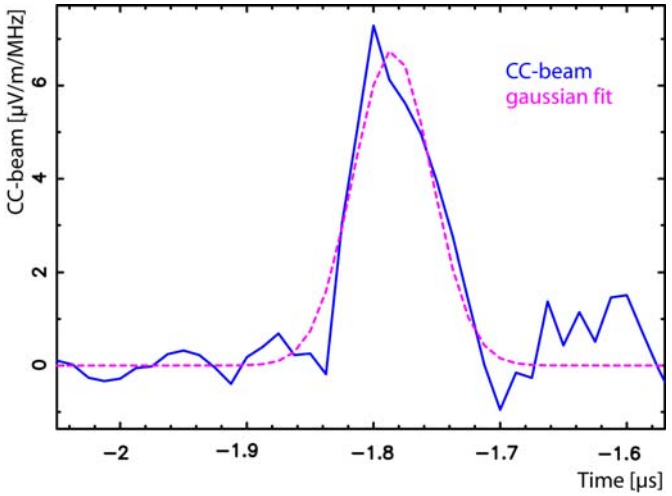
$$cc[t] = \pm\sqrt{\left|\frac{1}{N_{Pairs}}\sum_{i=1}^{N-1}\sum_{j>i}^{N} s_i[t]s_j[t]\right|}$$

(degree of correlation ➔ extract coherent pulse):



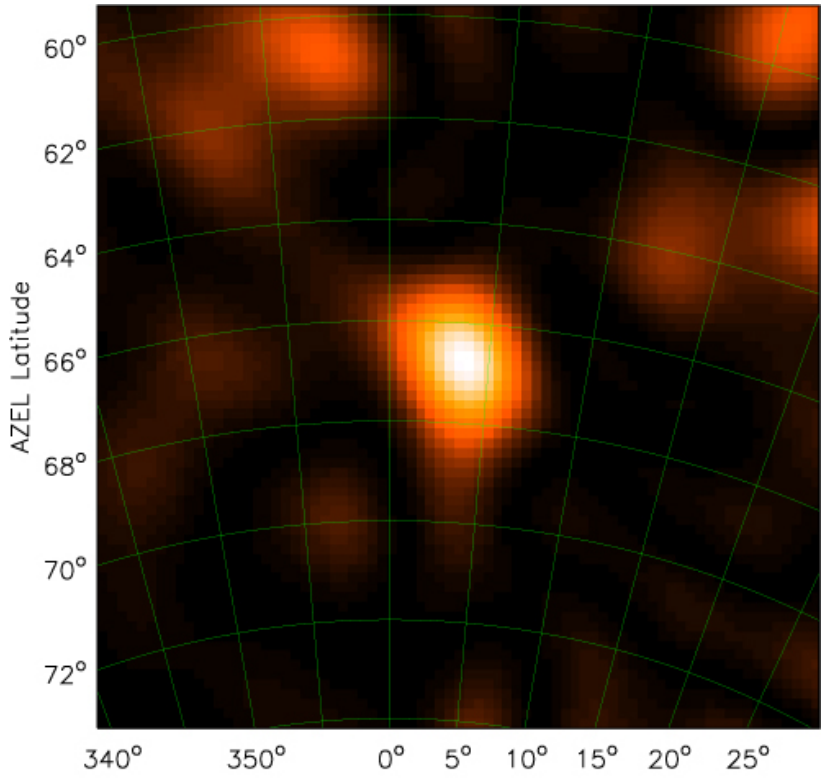
Event:
Φ = 15° θ = 306°
core = in KASCADE
lg(N_e) ~ 7.4
lg(N_μ) ~ 6.0
E_0 ~ 1.6·10^{17} eV



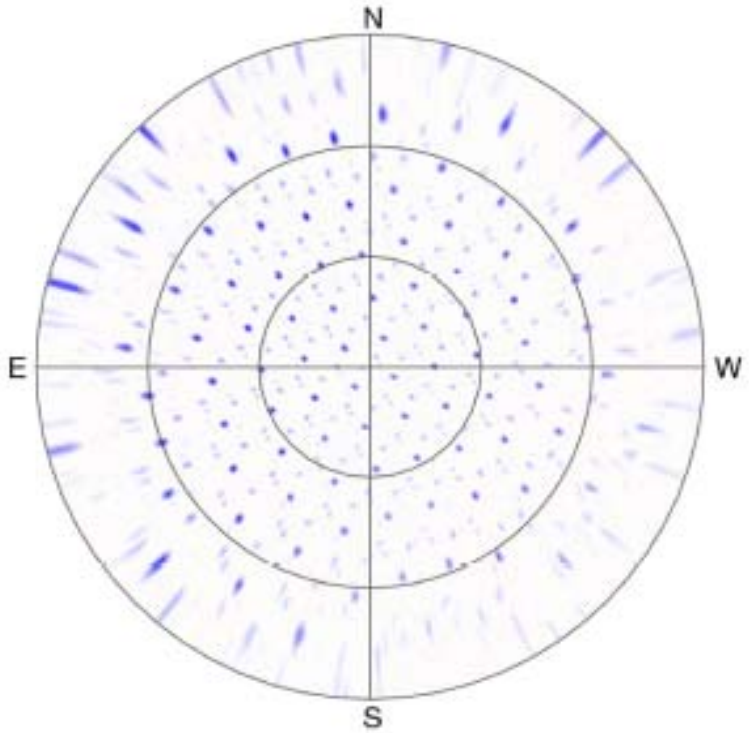


Beamforming - Skymapping

= skymap: beamforming at each point at the sky
-Pattern by constructive or destructive interference
-Pattern depends on array geometry
-LOPES: worse resolution under large zenith angles



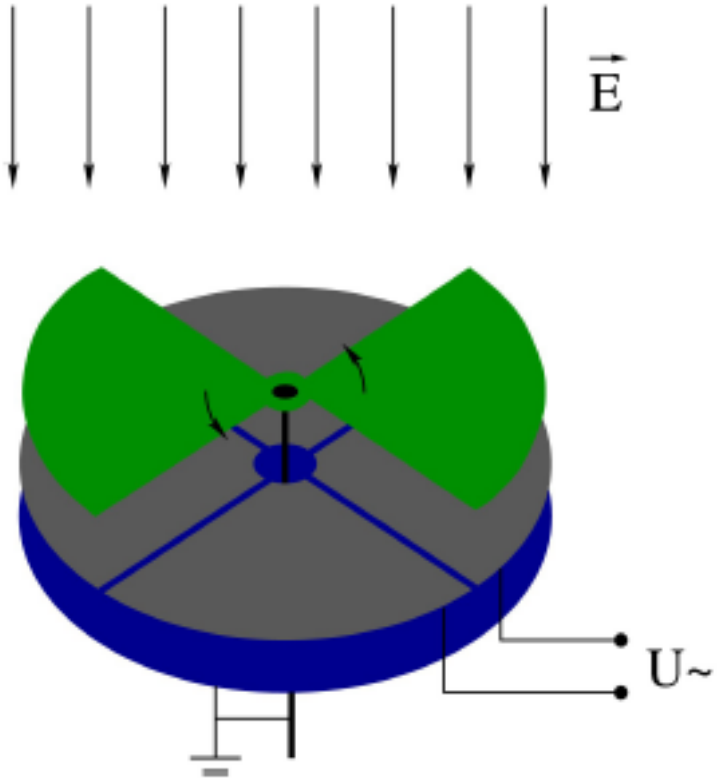
Zoom to a EAS signal



Geometric pattern

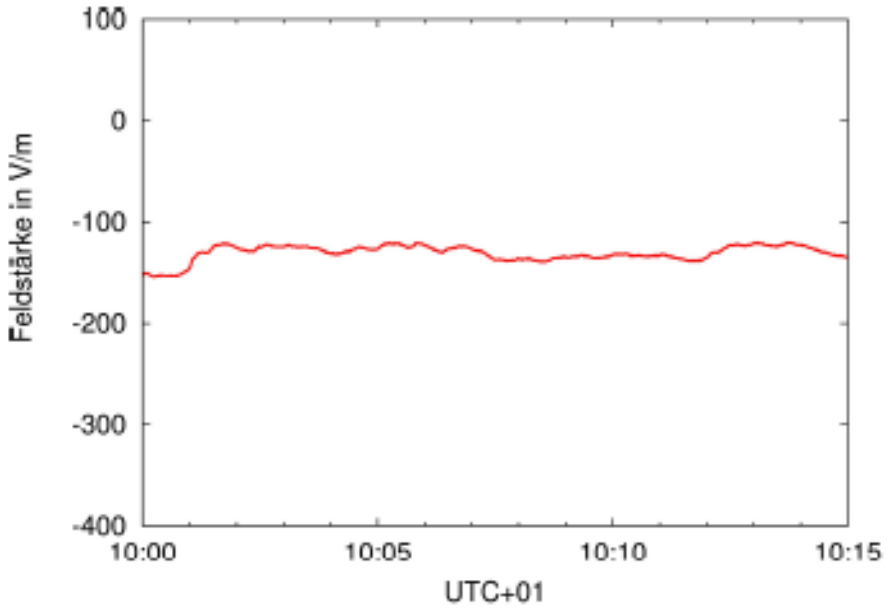
Measurements of the Electric Field

-E-field mill gives Voltage every second

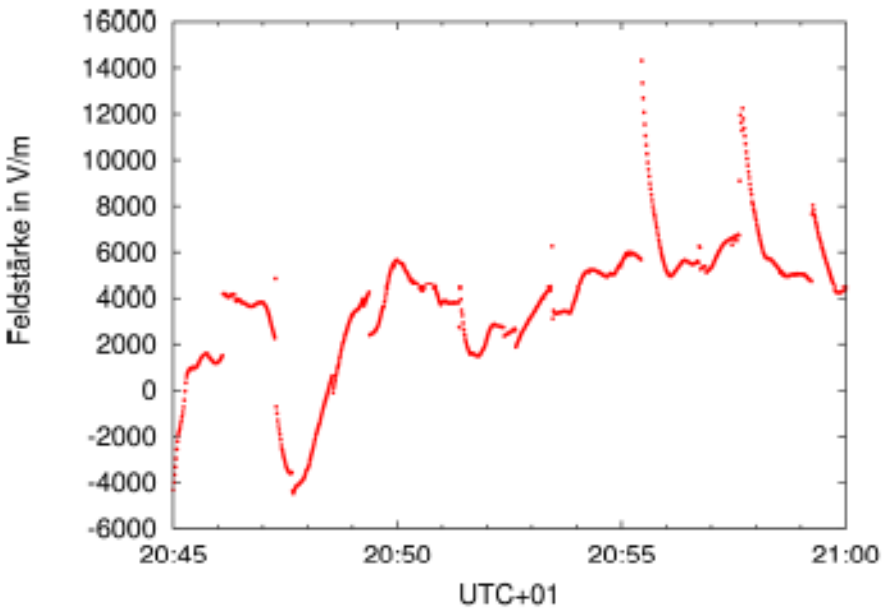


Measurements of the Electric Field

E-field during nice weather

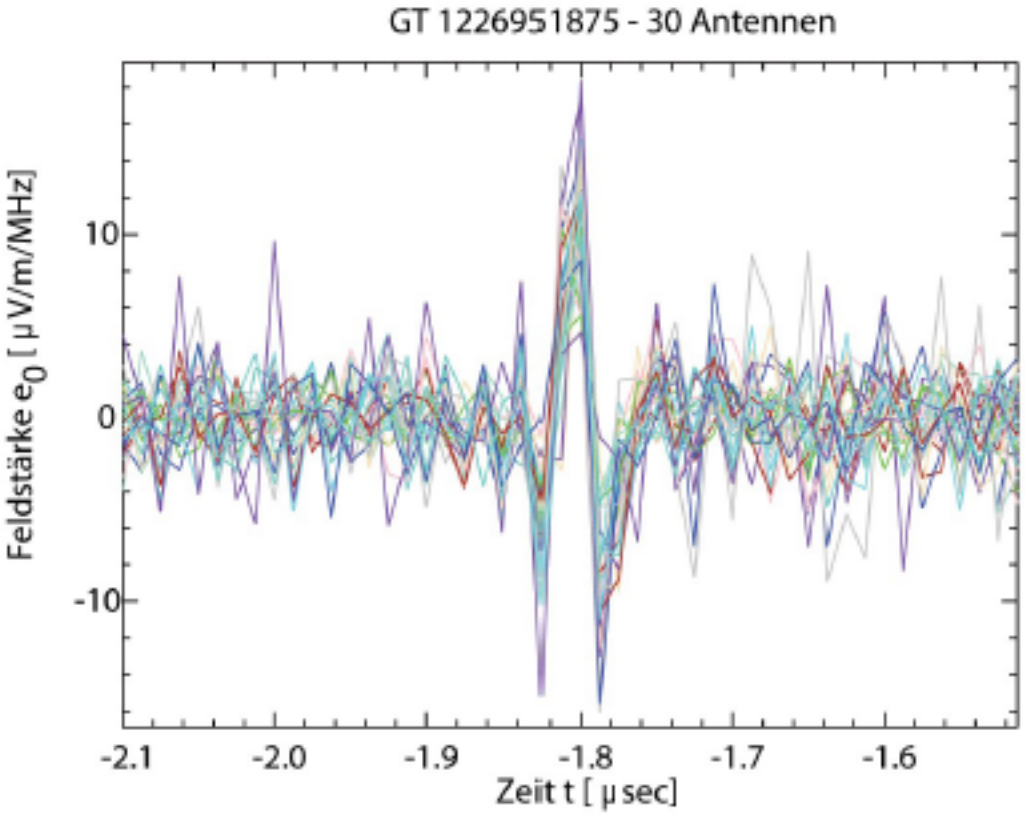


E-field during thunderstorm



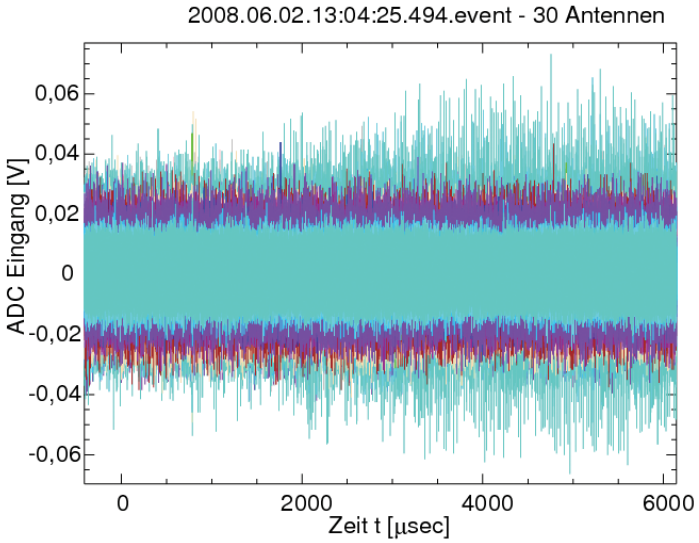
-Unique signatures during thunderstorms
-Used as automatic thunderstorm detection
➔ LOPES changes in thunderstorm mode = recorded time traces much longer

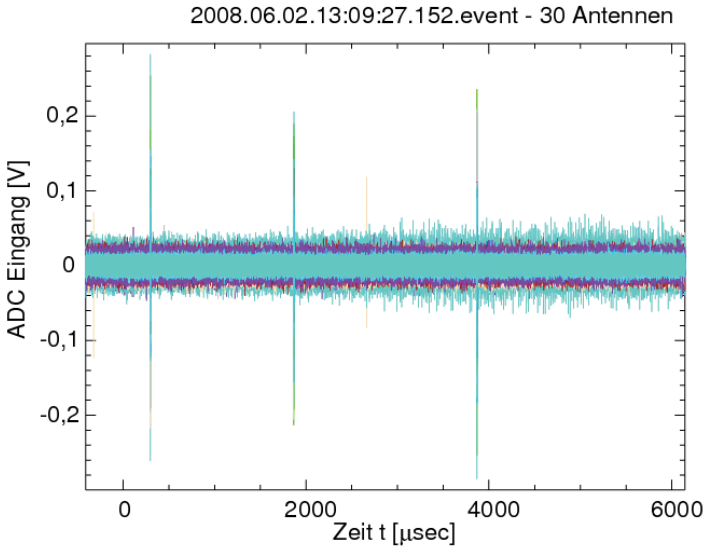
Radio Background during Thunderstorms

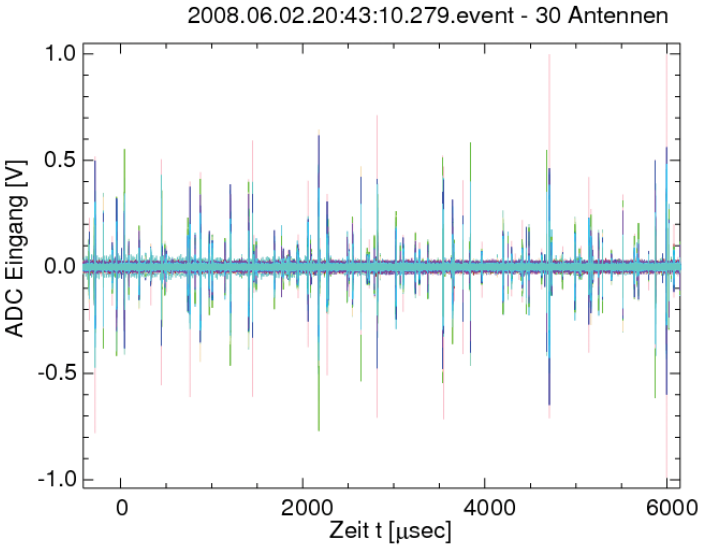


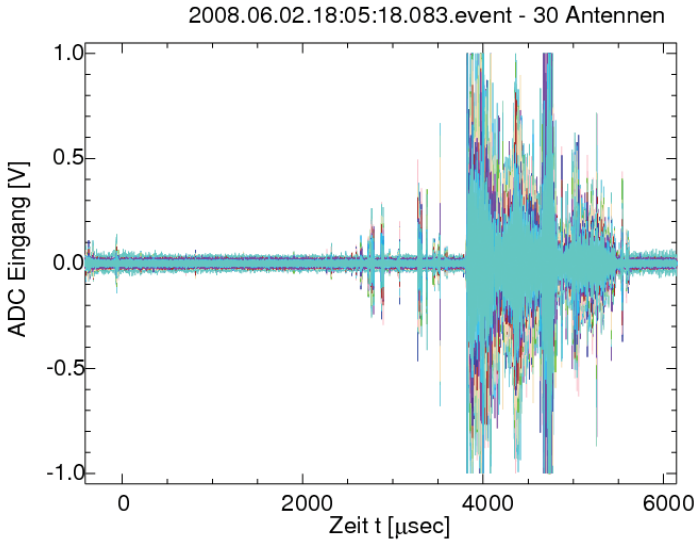
To remind recorded data for a nice EAS event!

Radio signals during lightning

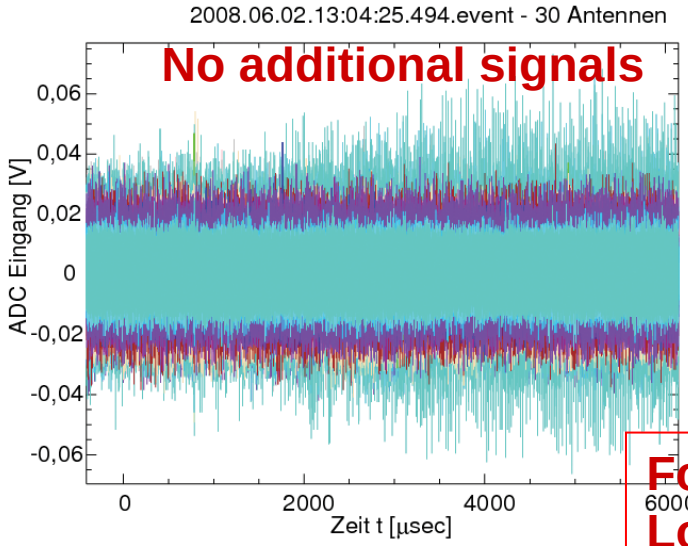


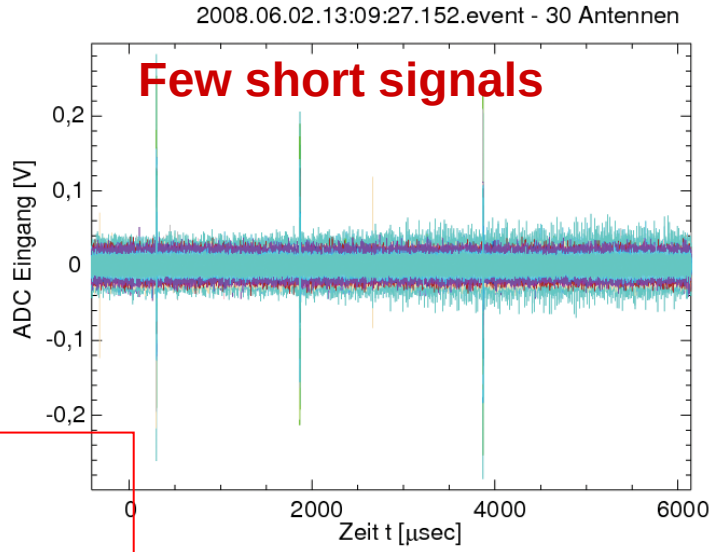




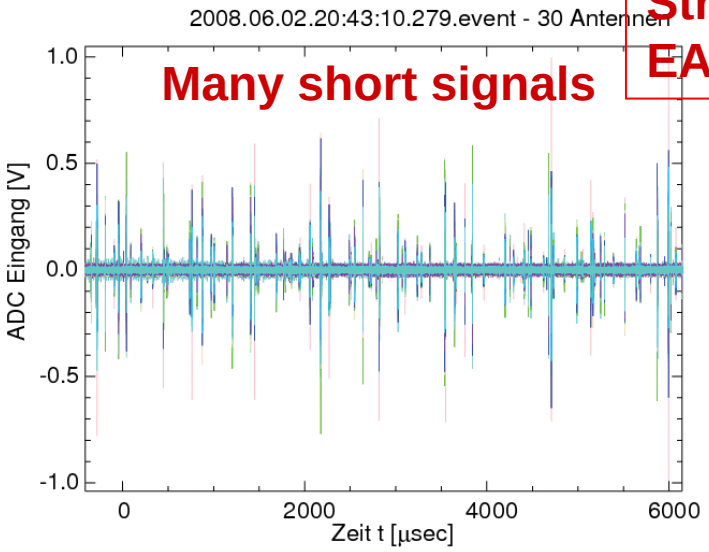


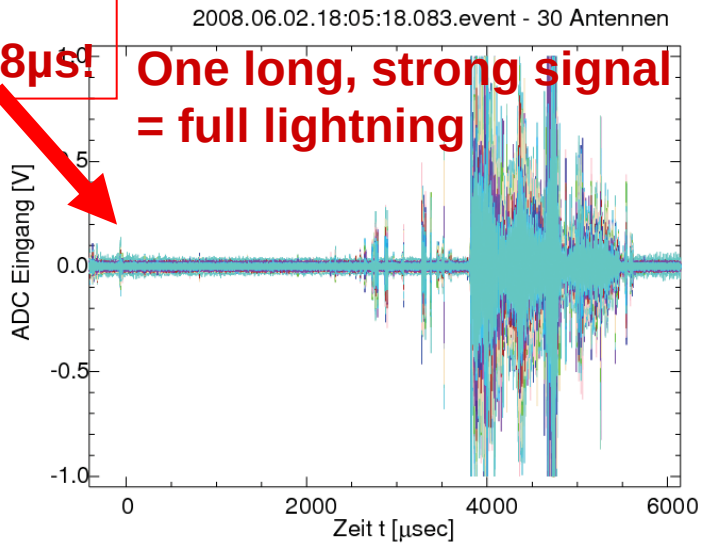
Radio signals during lightning





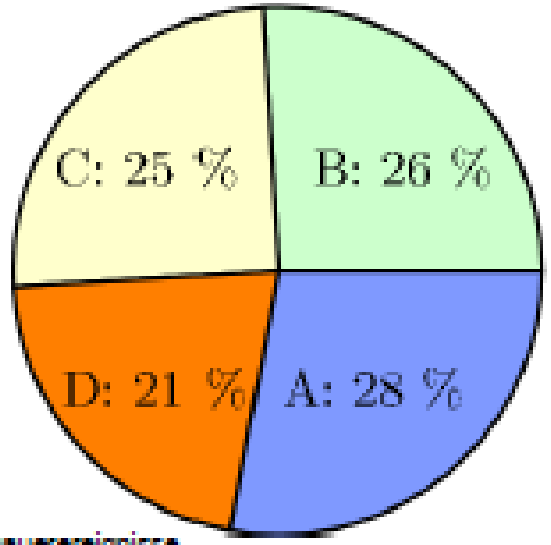
For all:
Longer trace!
Strong signals!
EAS signal at -1.8µs!





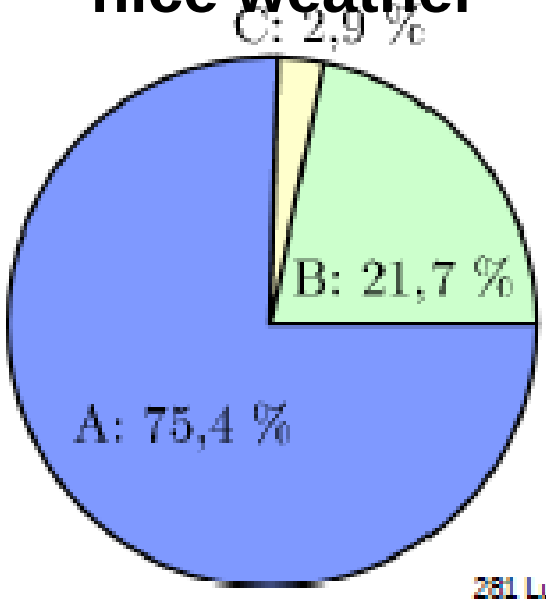
Radio Background during Thunderstorms

thunderstorm



2909 Luftschauerereignisse
(Jahr 2008)

nice weather



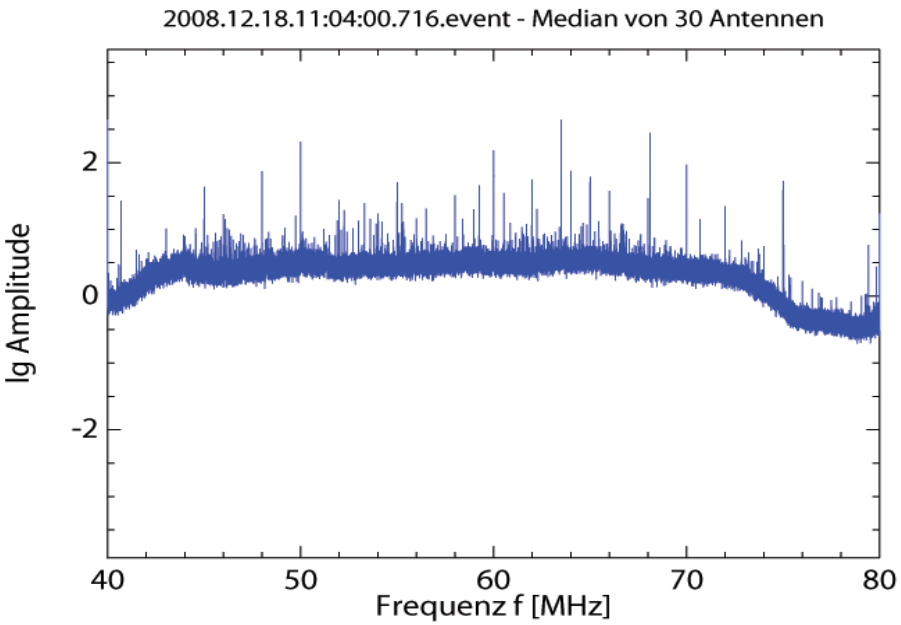
281 Luftschauerereignisse
(Künstlicher Gewittermodus)

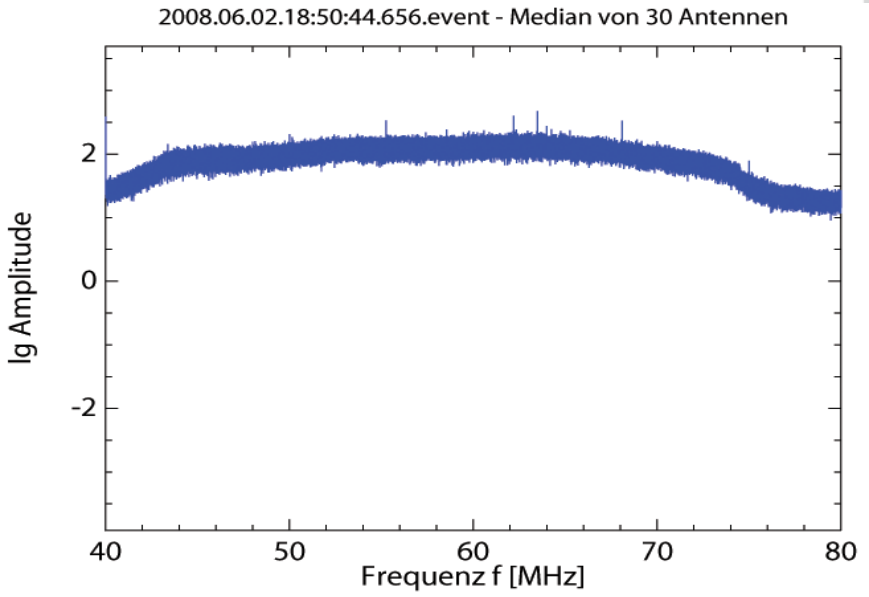
-Classification:

A: no additional signal
B: few short pulses
C: many short pulses
D: strong, long signal

➔ B is probably human RFI noise!
➔ D: in a quarter of EAS triggers we have a lightning development recorded (not detailed analysed yet)!

Radio Background during Thunderstorms





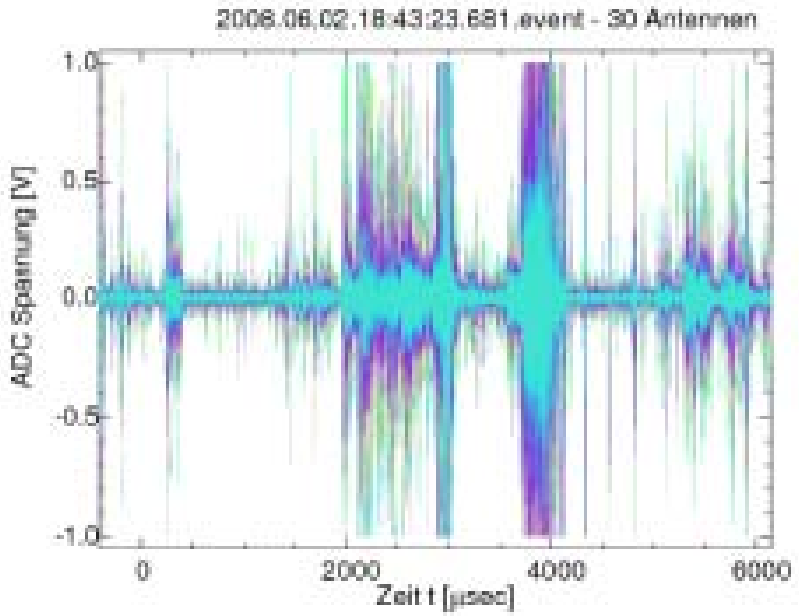
Higher background during thunderstorms

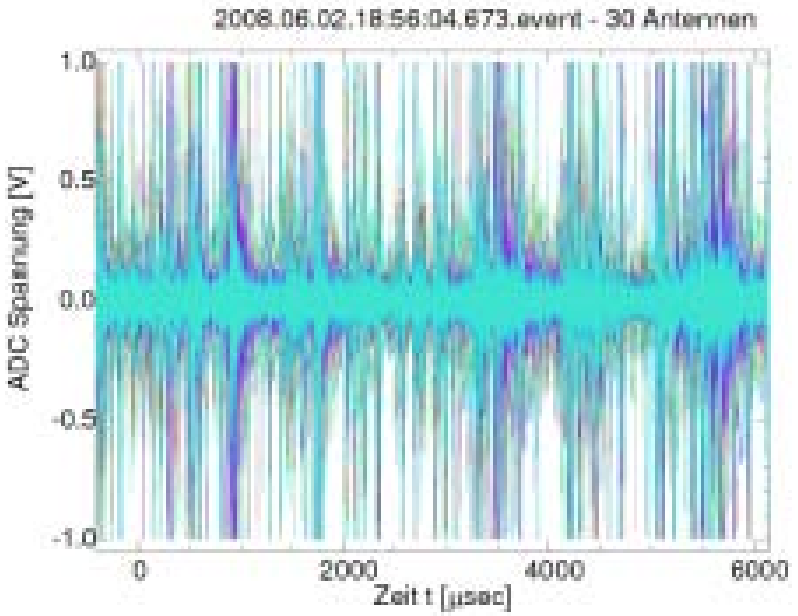
➔ Smallens signal-to-noise ratio of EAS data.

M. Ender, ICRC09, Lodz

Radio Background during Thunderstorms

Sometimes even saturated events

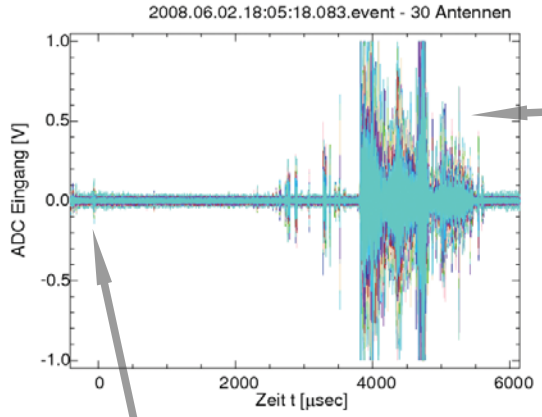




-Strong signal hides EAS-radio signal
-Saturation leads to artefacts in standard analysis
-Phase calibration not possible
➔ Thunderstorms are missing duty cycle in EAS measurements

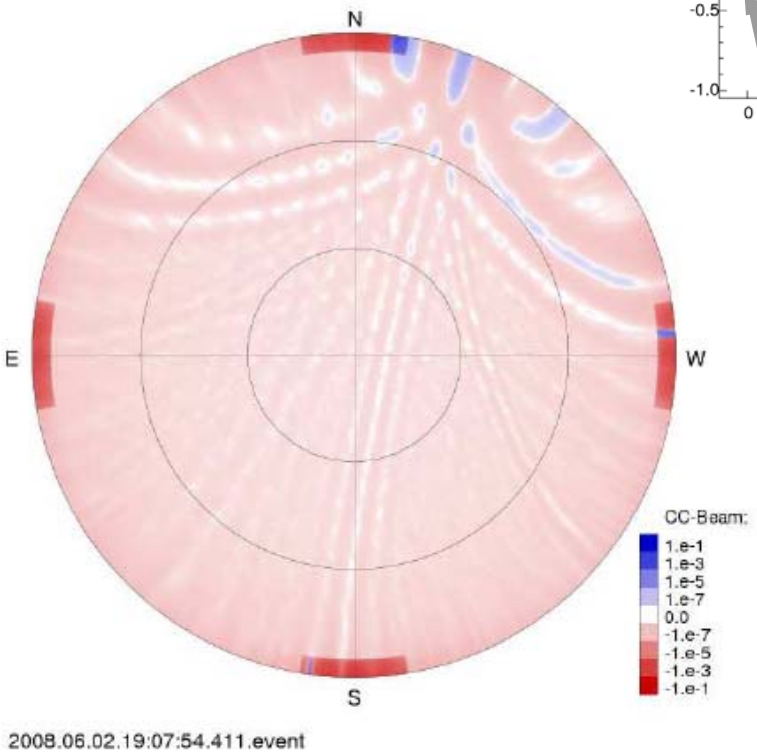
Lightning mapping with LOPES

(Moses Ender, Diploma thesis, KIT)



Lighning!
Short time here (as long as EAS) is used!

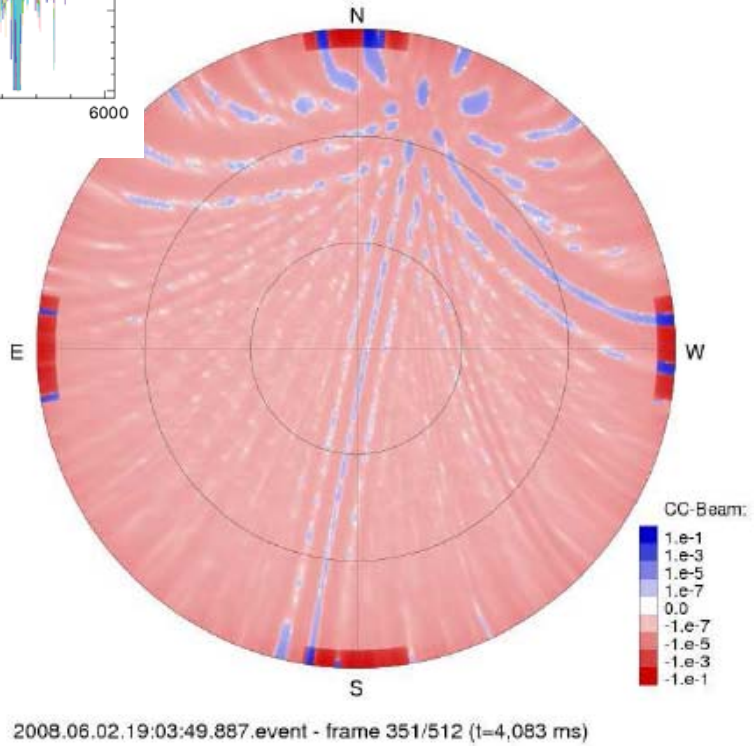
EAS



2008.06.02.19:07:54.411.event

Cloud to ground lightning

as signal goes to horizon



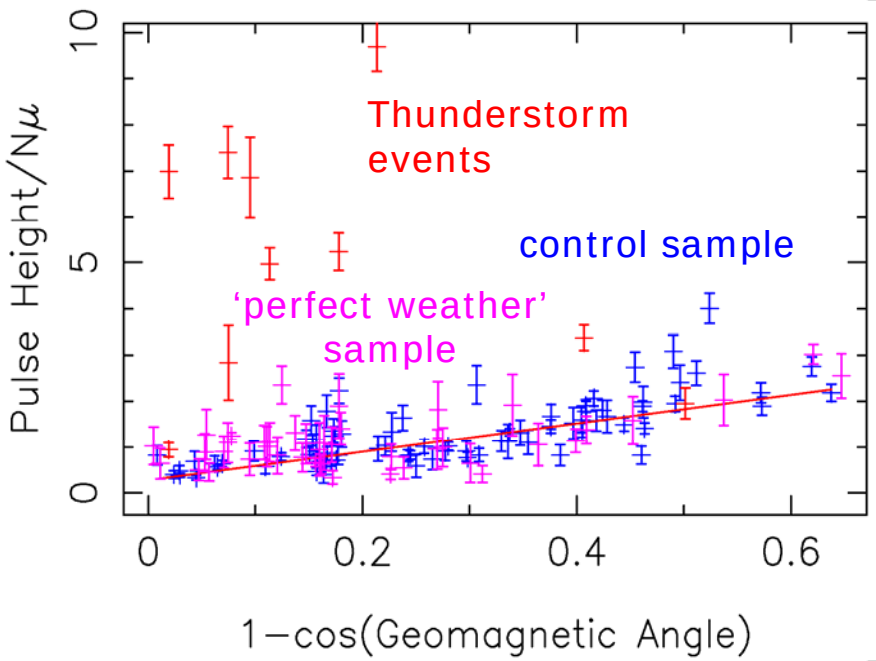
2008.06.02.19:03:49.887.event - frame 351/512 (t=4,083 ms)

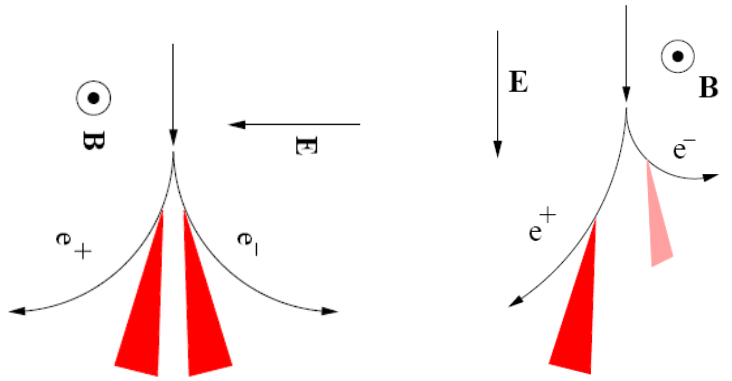
Intercloud discharge

as signal goes not to horizon

Influence of large E-fields to EAS measurements

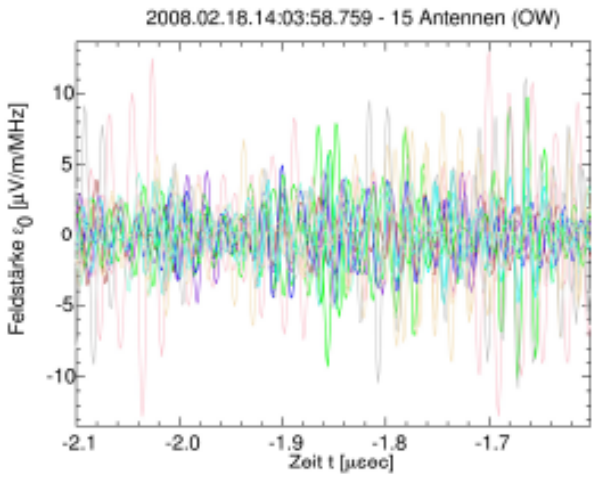
- **For E>10 kV/m E-field force dominates B-field:**
  - **Fair weather: E=100 V/m**
  - **Thunderstorm: E=10 kV/m**
- **E-fields have two main effects depending on geometry:**
  - **Additional curvature of $e^{\pm}$**
  - **Linear acceleration of $e^{\pm}$**
- **One does not see EAS where radio emission is decreased!**

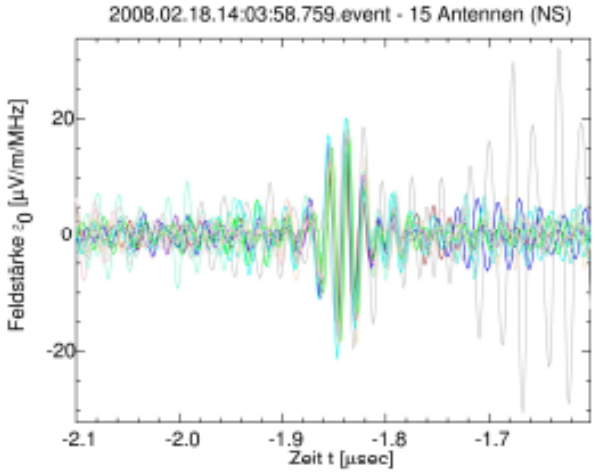




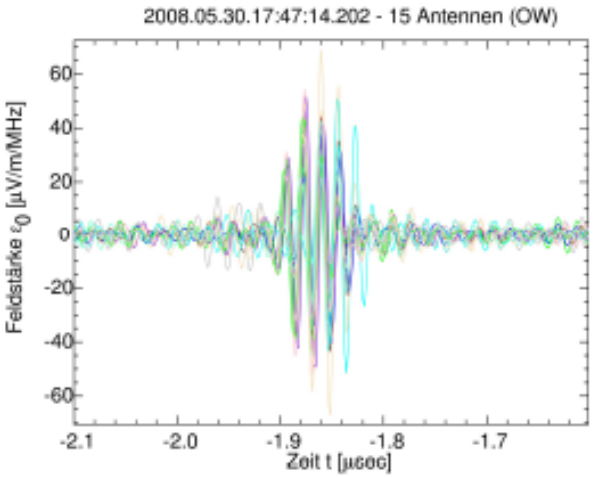
Buitink et al. (LOPES coll.) A&A 467(2007)385

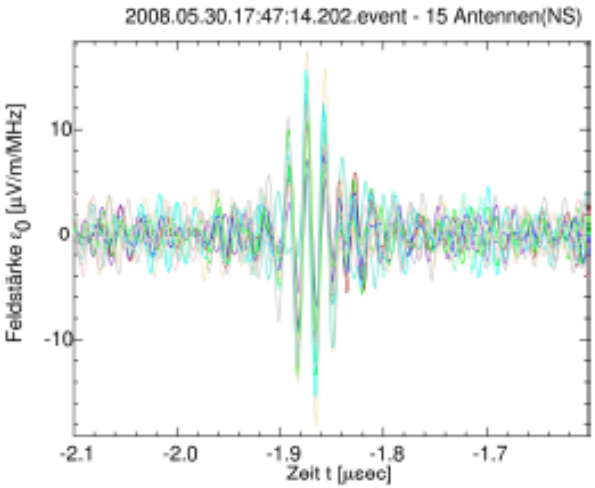
Influence of large E-fields to EAS measurements





Normales Ereignis:
Az: 104,5°
Ze: 44,6°
E=3,2 10^17

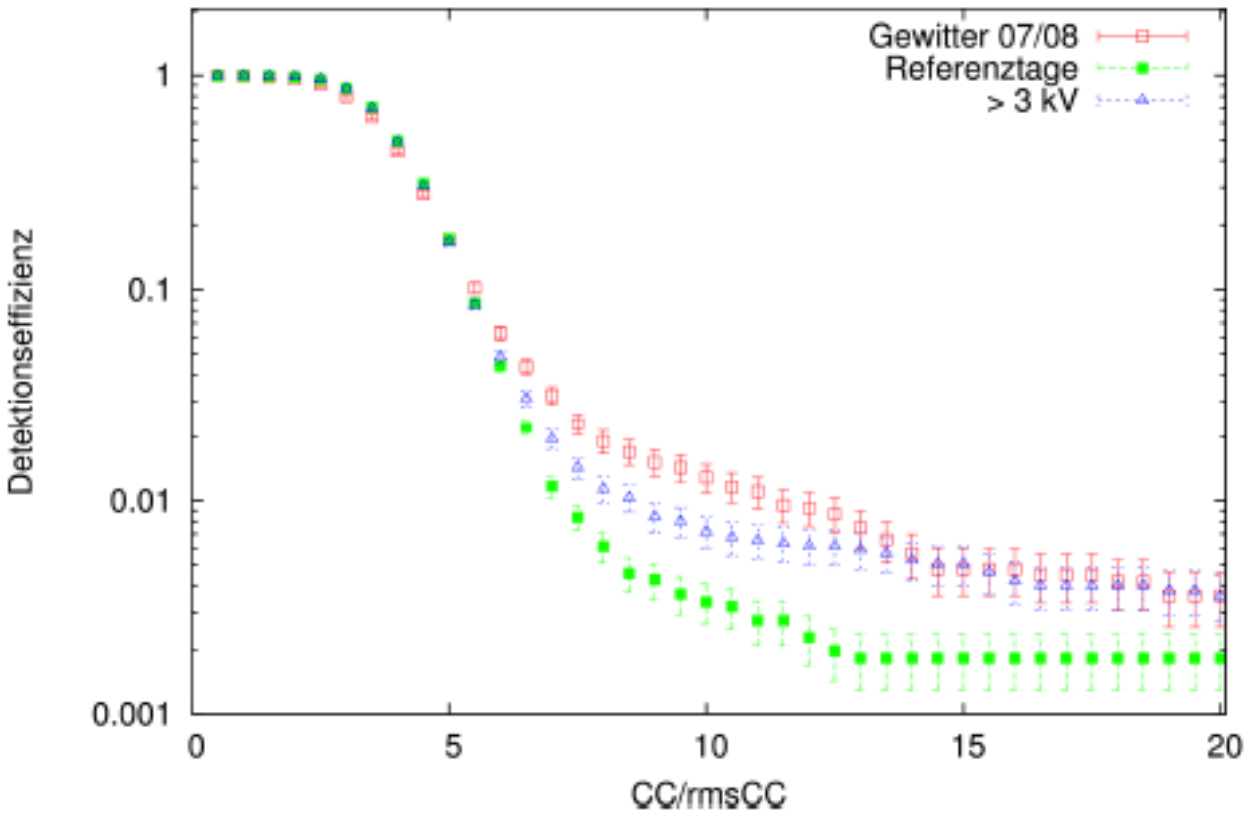


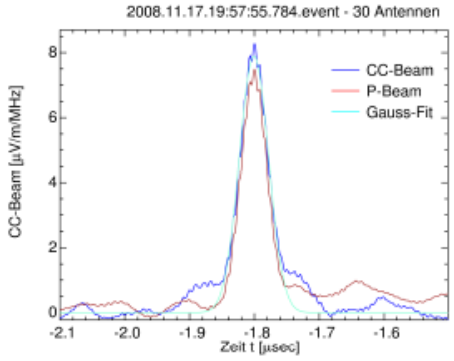


Similar event!
Clear enehancement
Of signal during
Thunderstorm!

Gewitterereignis:
Az: 104,5°
Ze: 50,1°
E=4,0 10^17

Influence of large E-fields to EAS measurements





Detection efficiency
During
Thunderstorm
Nice weather
High E-field (but no TS)

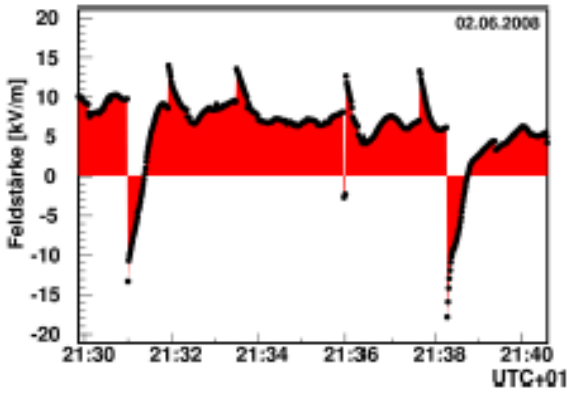
-Amplification effects clearly visible during thunderstorms!
-Can also happen outside thunderstorms (but large E-fields)

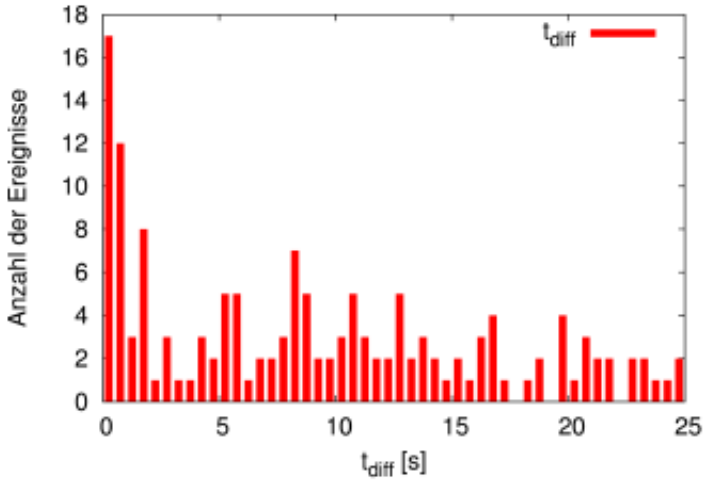
Correlation of EAS and Lightning?

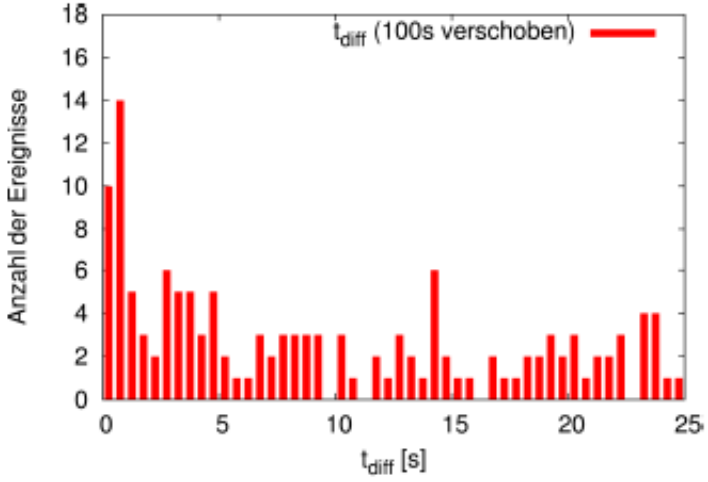
Time Coincidence?

Comparing E-field mill jumps (=lightning) with air shower time in 1 second bins!

(Enhancement at zero not significant as also seen when t-diff shifted by 100s)





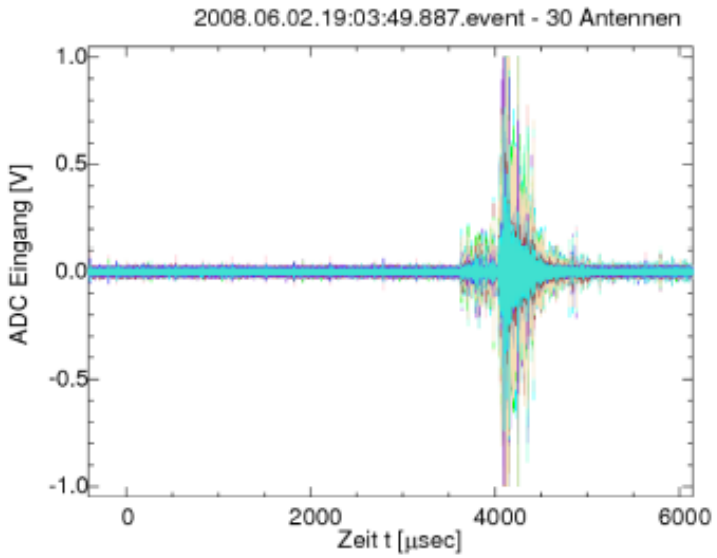


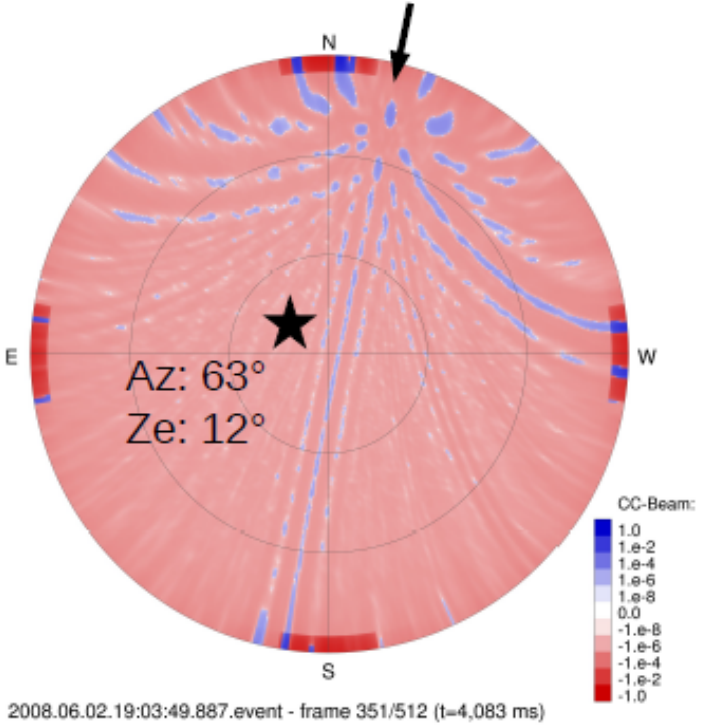
-Nothing seen!

Correlation of EAS and Lightning?

Spatial Coincidence?

Event example: skymapping of lightning
And black star shows the position of EAS





-**Nothing seen!**

Future Studies planned! With

- **LOPES-3D**

  40-80 MHz

- **E-field mill**

  thunderstorm monitoring

- **KASCADE-Grande**

  particles

- **kHz antenna**

  kHz

- **Lightning mapping array**

  location of individual lightning

- **GHz antenna**

  GHz (new idea!)

Summary

- ➔ **Broadband signals during thunderstorms hampers the detection of air showers with the radio detection technique**

  reduction of duty cycle (100% ➔ 95%)

- ➔ **Strong electric fields have influence to EAS radio detection**

  Monitoring needed

- ➔ **Correlation between cosmic ray and lightning not (yet) seen**

  full potential of LOPES-thunderstorm mode not explored

- ➔ **multi-hybrid observations needed**

  Talk on Friday