CROME experiment and its results

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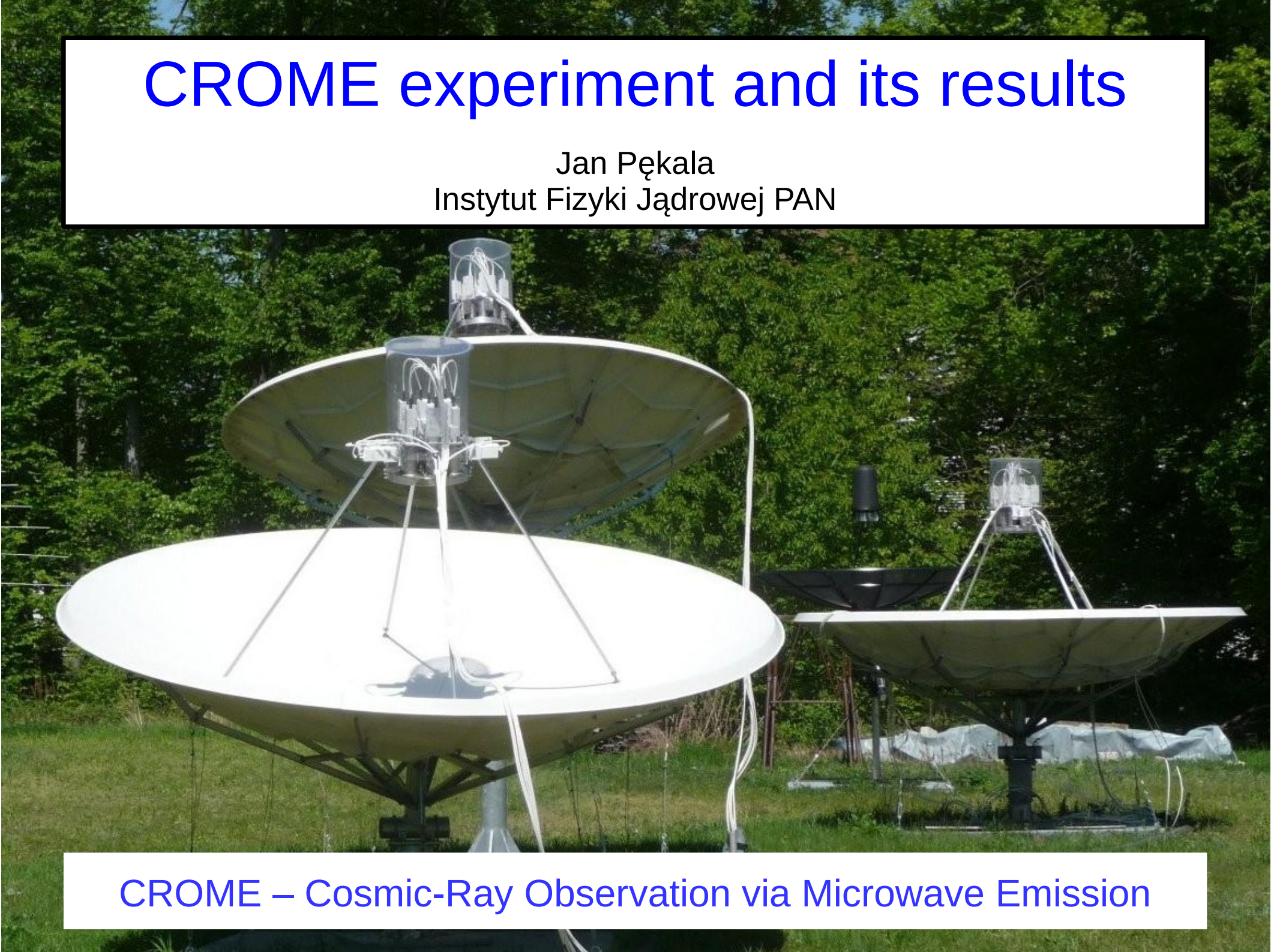
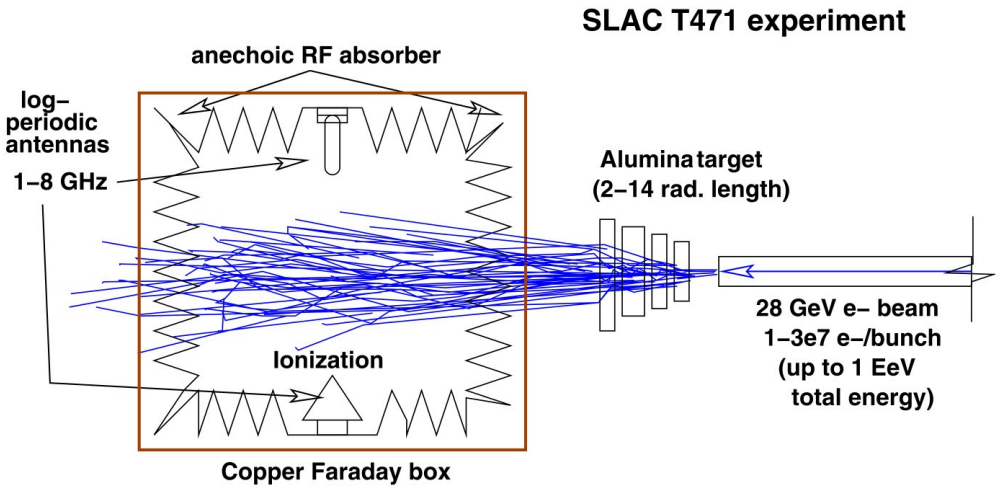


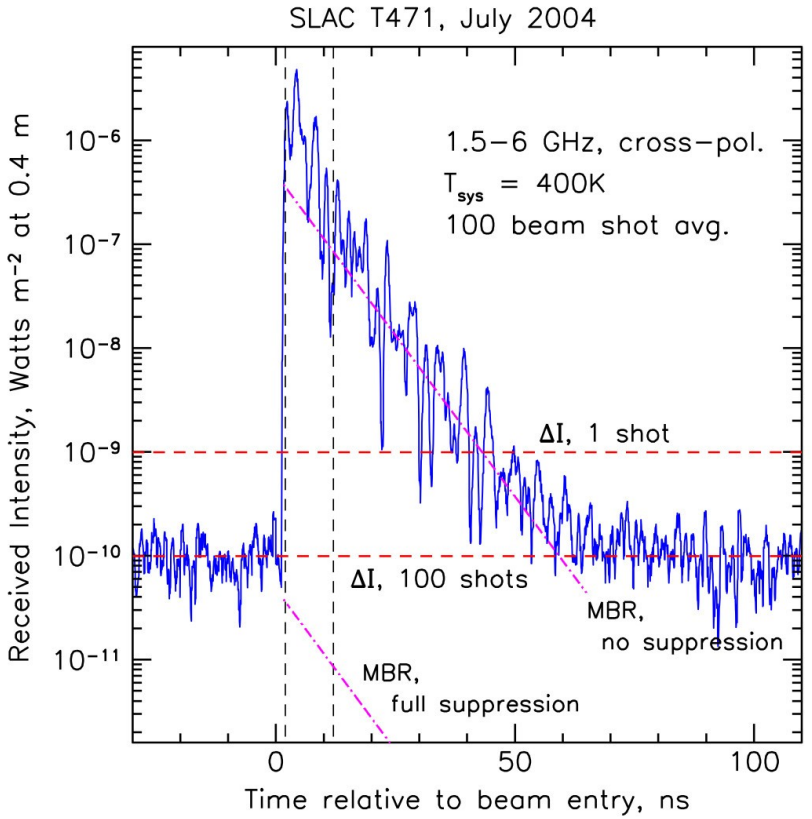
CROME – Cosmic-Ray Observation via Microwave Emission

Molecular bremsstrahlung from air showers?

Experimental evidence for molecular bremsstrahlung radiation has been presented (Gorham et al., Phys Rev D 78 (2008) 032007).

The passage of charged particles of air shower produces plasma in the air.
Free electrons could emit microwave photons.
⇒ **Isotropic, unpolarized microwave emission should be detectable.**

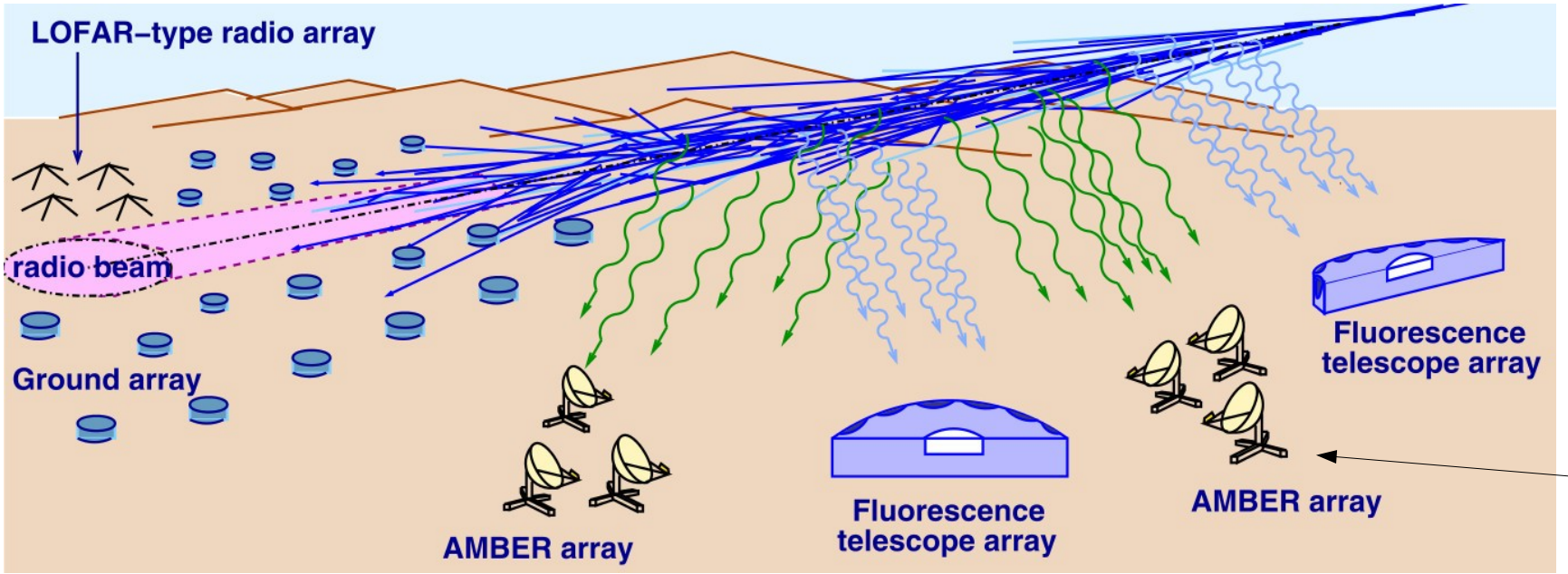




New technique of air shower observation?

Possibility of developing a new method of air shower observations:
- very low natural background,
- transmission not obstructed by atmosphere,
- observation possible 24 hrs/day,
- easily adaptable technology available (satellite TV).

Experimental tests needed for confirmation.



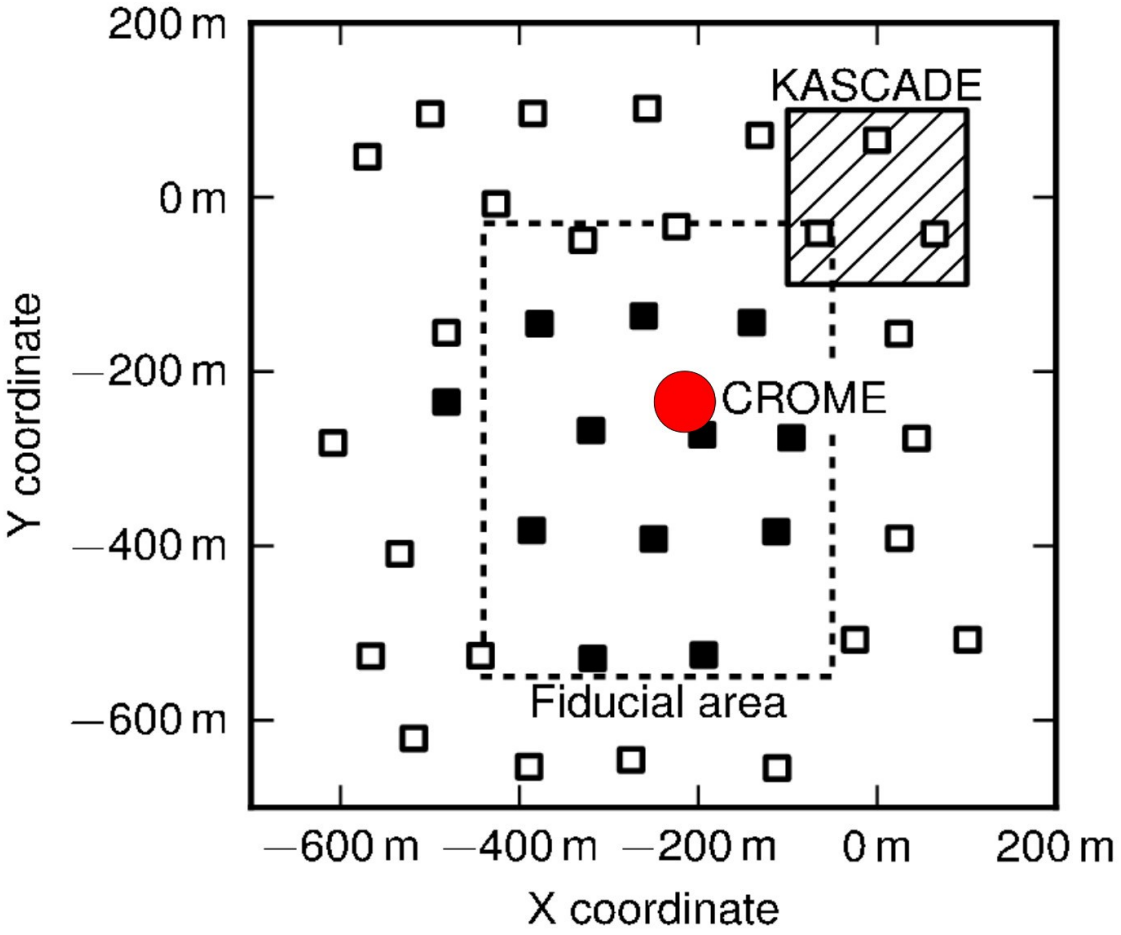
Cosmic-Ray Observation via Microwave Emission
Location and external trigger

CROME experiment was operating with KASCADE-Grande trigger:
May 2011 – November 2012

Array of radio antennas recording signal in several bands.

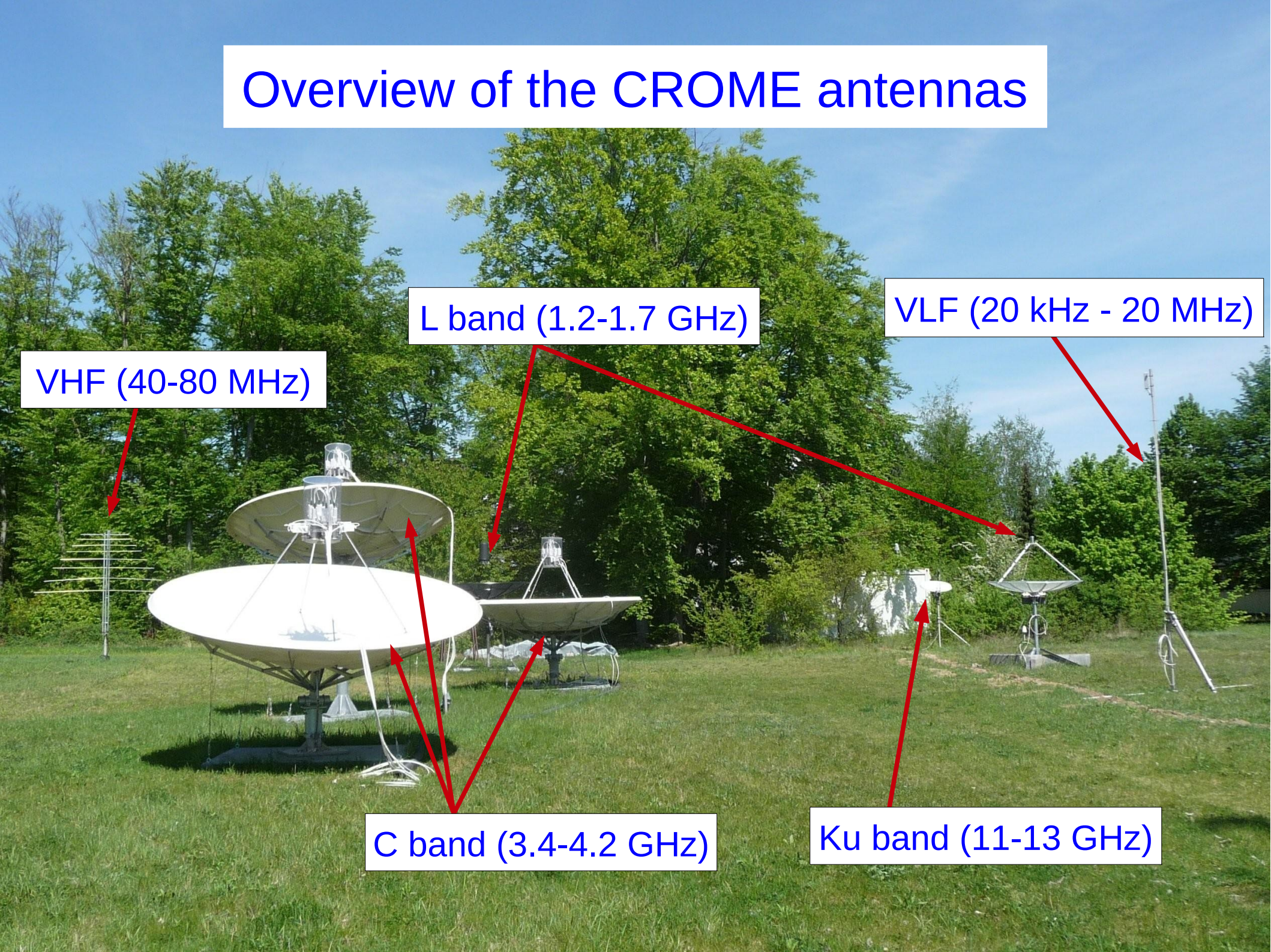
Triggered by air showers with energies 10^{15} – 10^{18} eV.

Precise reconstruction of showers detected by KASCADE-Grande:
- 0.8° for the arrival direction,
- 6 m for the position of shower axis,
- 20% for the energy.



CROME located in the center of KASCADE-Grande (Karlsruhe Institute of Technology).

Overview of the CROME antennas



Observation in the C band (3.4 – 4.2 GHz)

The C band is used for satellite communication.
Low natural background.
Negligible atmospheric attenuation.

Commercial parabolic reflectors (335 cm diameter).

Antennas pointed upward – minimization of the distance to the shower maximum.

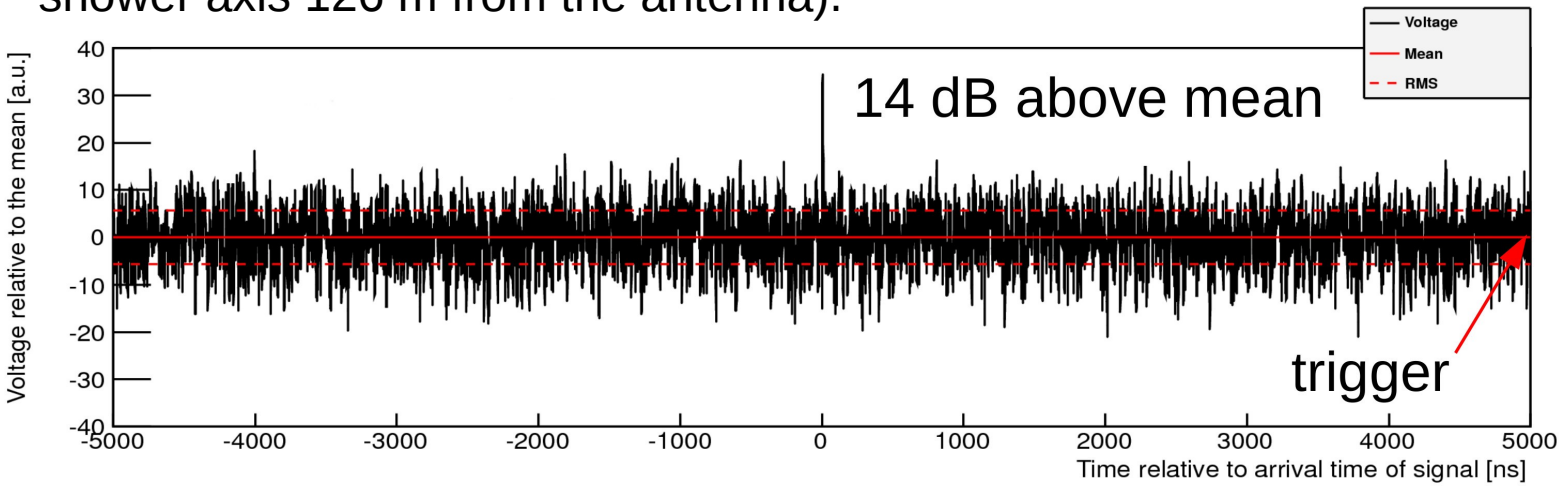
Two of the antennas tilted by 15° North and South to observe showers with different angles relative to the local geomagnetic field.

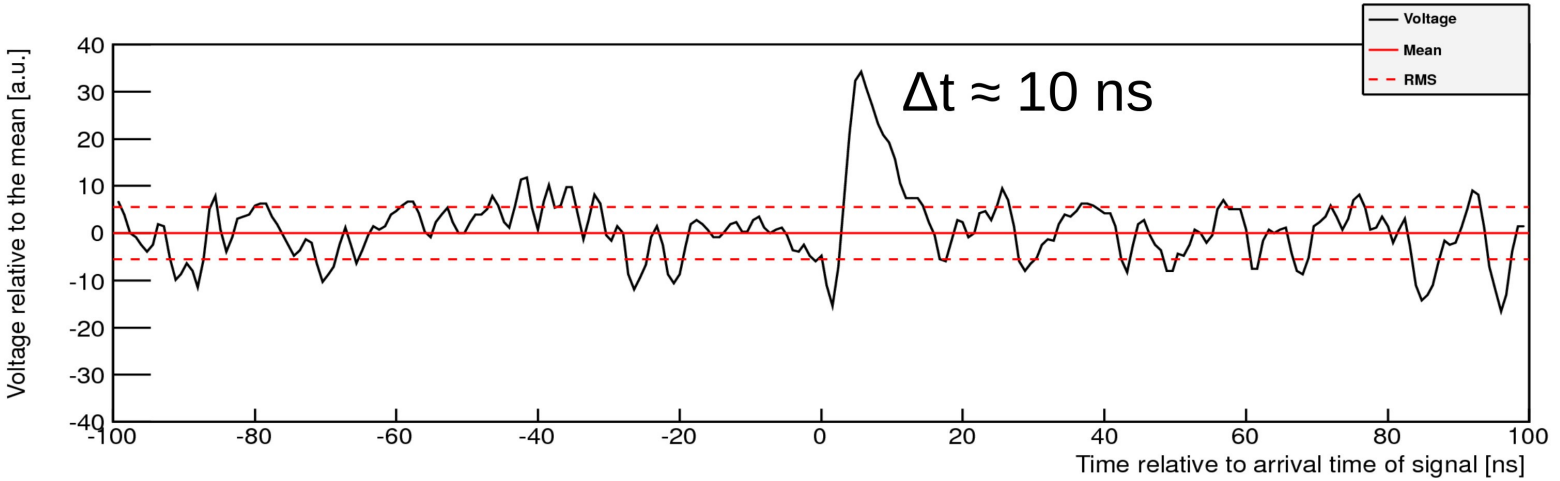
13 linearly polarized receivers in a camera.

Finding microwave signal

Readouts were recorded for a time of 10 μs before and after each KASCADE-Grande trigger.

An example of the recorded signal (shower energy 9×10^{16} eV, shower axis 126 m from the antenna).

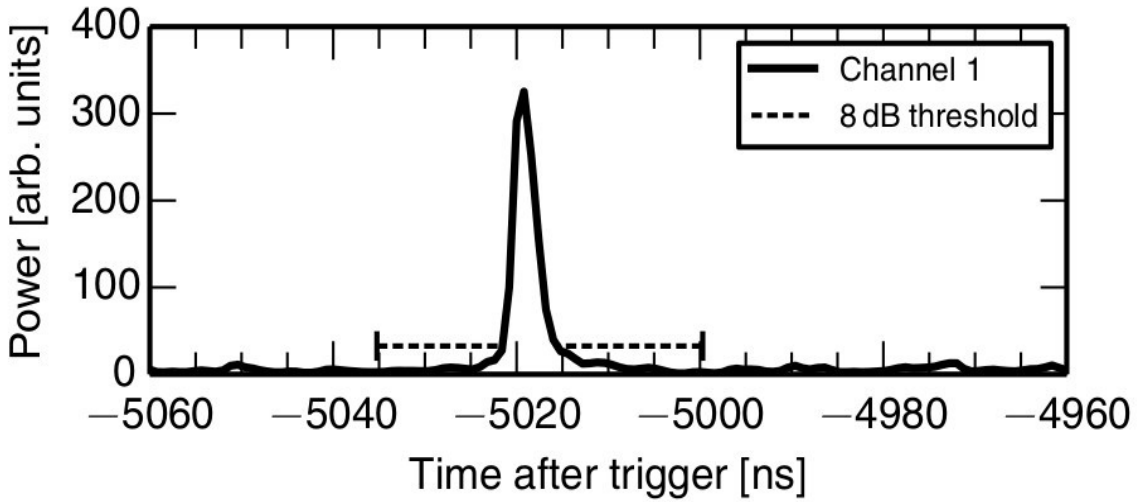




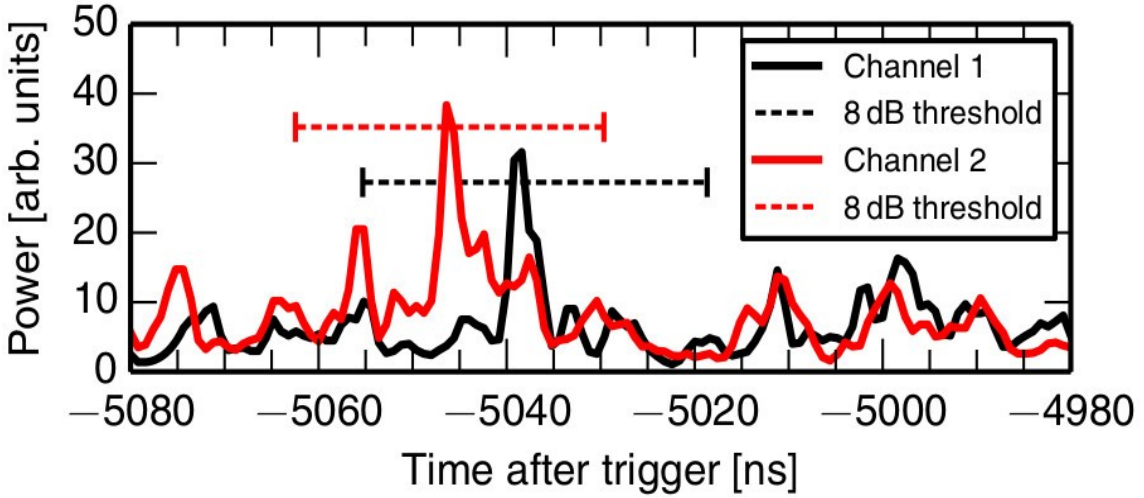
Results – examples

Event selection – signal at least 8 dB above the mean noise level.

Highest signal: 17.7 dB
Energy = 2.5 × 10^{17} eV
Zenith angle = 5.6°
Distance = 120 m

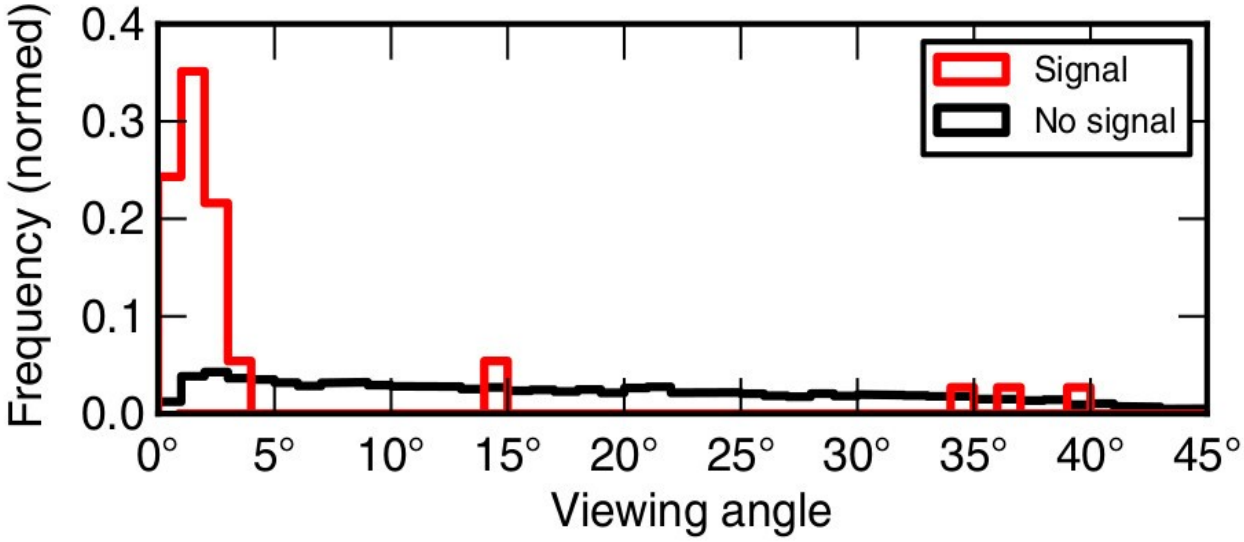


Stereo event
Signals: 8.2 and 8.5 dB
Energy = 3.7 × 10^{16} eV
Zenith angle = 3.7°
Distance = 110 m



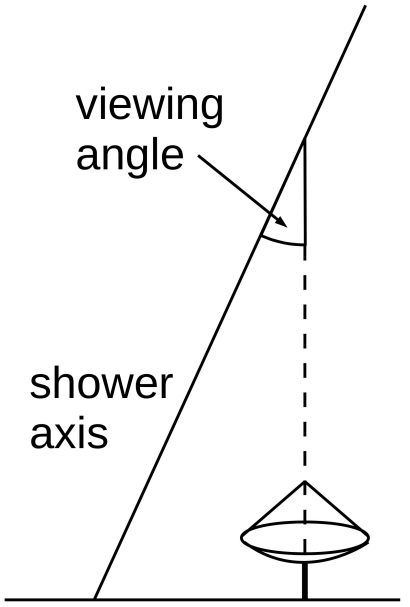
Results – event selection

Cuts on data used in analysis:
- Shower energy > 3×10^{16} eV,
- Shower axis within field of view of at least one receiver (2°),
- Signal within $\Delta t \approx 50$ ns from expected arrival time,
- Signal > 8 dB above noise.



With these conditions applied, there are 37 event candidates with microwave signal from the KASCADE-Grande showers. Expected number of noise signals is 9.4 ± 0.2.

After introducing a cut on viewing angle < 4°: 31 showers with microwave signal. Expected number of noise events is only 1.1 ± 0.1.



Radio emission from extensive air showers

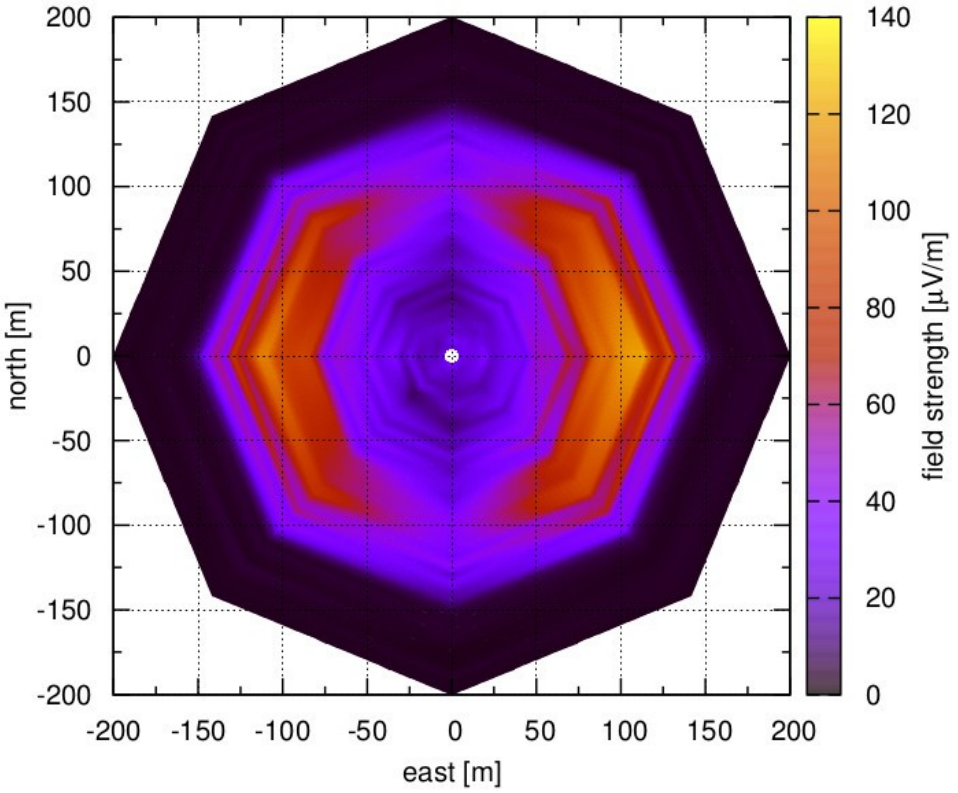
Sources of emission:
- charged particles deflected in Earth's magnetic field – geomagnetic radiation,
- more electrons than positrons in air shower – Askaryan effect.

Signal observed in the MHz range, but suppressed for shorter wavelengths.

Near the Cherenkov angle, time compression effects are expected – this should enable observations in the GHz range.

CoREAS – CORSIKA-based program for simulation of radio signals from extensive air showers.

Predicted signal in the 3.4-4.2 GHz band, from a vertical 10^{17} eV shower induced by a proton.



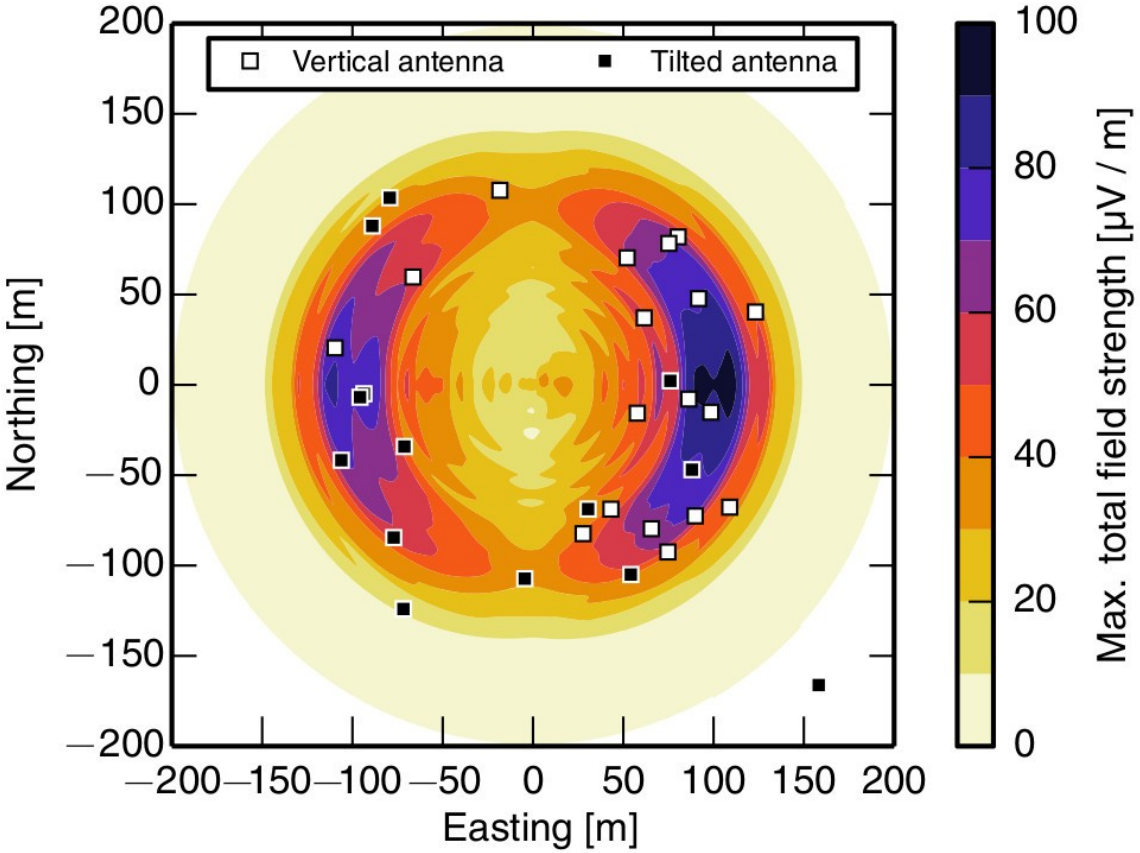
Results – interpretation

Reconstructed positions of shower cores form a ring structure around the antennas.

High signals at the Cherenkov angle relatively to the air shower axis – **consistent with time compressed geomagnetic radio emission**.

Stronger signals for showers with larger angles relative to the local geomagnetic field.

East-west asymmetry in the field strength – addition from Askaryan effect?



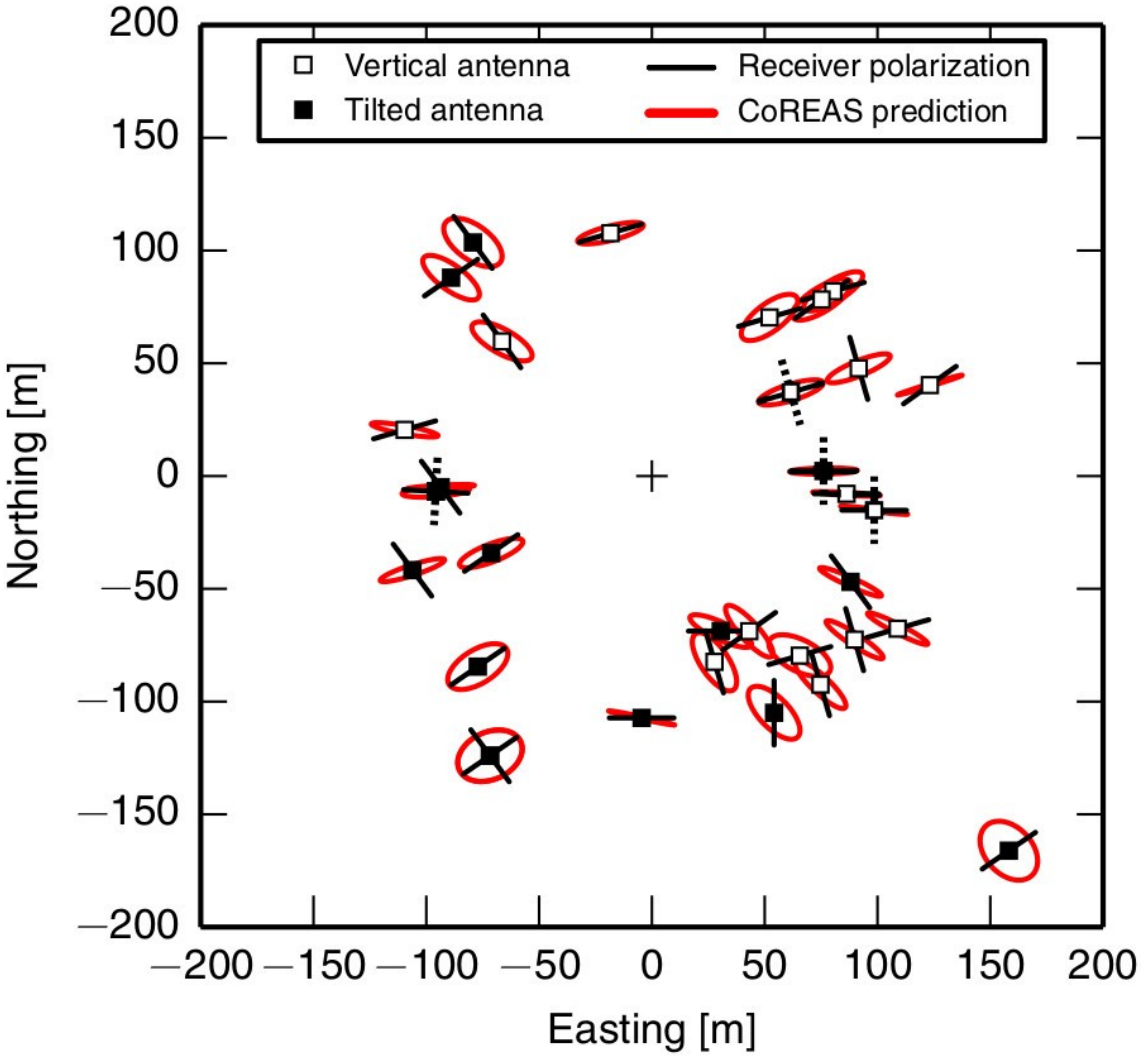
CoREAS prediction for a vertical shower 10^{17} eV and X_{max}= 658 g/cm^2

Results – polarization

Polarisation pattern consistent with the geomagnetic radio emission.

Statistical analysis rejects the unpolarized microwave emission with 5 σ significance.

(Molecular bremsstrahlung is expected to be unpolarized.)



Polarization directions of receivers with microwave signal and the CoREAS prediction.

Summary

CROME recorded microwave emission from over 30 extensive air showers.

The measurements show that microwave radiation offers a new means of studying air showers.

Evidences for time compressed geomagnetic and Askaryan radio emission:
- small viewing angle (close to the Cherenkov cone) relative to air shower axis,
- dependence on the angle relative to geomagnetic field,
- east-west asymmetry.

Measured microwave signal is polarized.

⇒ **The molecular bremsstrahlung is NOT the dominant emission mechanism of the microwave signals.**

More details in Phys. Rev. Lett. 113, 221101 (2014)