Measurements with the absolute calibrated L-band radio antenna of CROME for extensive air showers

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Abstract. The Cosmic-Ray Observation via Microwave Emission (CROME) experiment is designed to study GHz radio emissions from extensive air showers. Multiple radio antennas measure externally triggered by the KASCADE-Grande air-shower array. The experiment is designed to detect a potentially isotropic, unpolarized component as expected by molecular bremsstrahlung emission in the low-energy electron plasma as indicated by a collider experiment.

This contribution shows the measurements using the L-band (1-2 GHz) antenna of CROME. An absolute calibration of the receiver system was performed successfully and could be used for a specific signal search. In addition, the measurement results were compared to expected field strengths of molecular bremsstrahlung and simulations of emission mechanisms as studied in the MHz region.

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CROME

The measurement goal of the Cosmic-Ray Observation via Microwave Emission (CROME) experiment was designed to detect microwave signals from molecular bremsstrahlung (MBR) initiated by extensive air showers (EAS) as predicted by [1]. Since this emission is expected to be isotropic, the longitudinal development of air showers could be detected with a duty-cycle of 100%, while being less sensitive to atmospheric effects than the measurements of fluorescence light. The prospect of this new measurement technique is to reconstruct energies and composition of cosmic ray primary particles for future detector systems with unprecedented accuracy. The experimental setup of CROME consists of several antenna dishes measuring in the L-Band (1-2 GHz), C-Band (3.4-4.2 GHz) and Ku-Band

FIGURE 1. Setup of the L-Band receiver System.

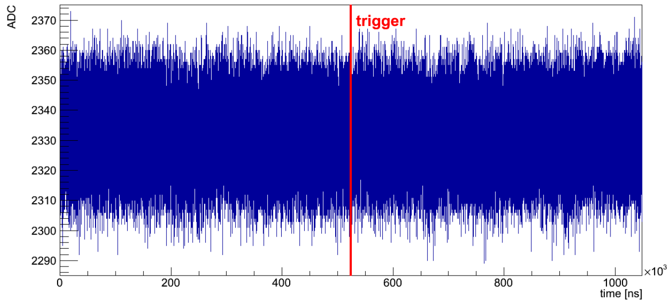

FIGURE 2. Example of the data output of the power detector centered around the KASCADE-Grande Trigger.

(10.7-12.7 GHz). Trigger signals for the data acquisition as well as reconstructed shower information were provided by the KASCADE-Grande air shower detector [2] until its final shutdown in November 2012. Using the C-Band antennas of CROME first successful measurements of microwave radio emissions from air showers have been published [3] [4] [5] and favor a coherent and polarised emission in contrast to the predictions of MBR. These characteristics can be well explained by emission processes describing the MHz emission [6] [7].

The L-Band Antenna

The measurements in the L-Band were performed using a 3.4 m parabol antenna dish (Fig. 1). Its antenna signals from a dipole in the antenna feed were amplified with a low-noise amplifier (LNA) and limited to a frequency range of $1050-1750$ MHz using a customized bandpass filter to avoid GSM disturbances. The input power was measured with a logarithmic power detector having an integration time of 4 ns and finally sampled with 250 MHz by a VME-card. For each air shower triggering all three KASCADE-Grande clusters surrounding the antenna a data trace of 1 ms length was recorded centered around its triggering time (Fig. 2). With this setup data were taken for two measurement periods from 23.06.2012 until 04.07.2012 and from 24.08.2012 until the shutdown of KASCADE-Grande on 05.11.2012 totalling to 85 days of measuring time. In between these measurement periods an amplifier with a larger gain was installed in the data acquisition, but since all measurements with this amplifier were largely dominated by disturbances, they could not be taken into account. Measurements before 24.05.2012 were performed with another receiver dish that had a smaller diameter of 2.3 m.

The data traces were cleaned automatically from short-term disturbances which were on the microsecond scale and thus much too long for signal candidates. Additionally all monofrequent signals were removed by smoothing peaks in the fourier transformed data traces.

ABSOLUTE CALIBRATION OF THE ANTENNA SYSTEM

To determine the measured field strengths of the radio antenna an absolute calibration was performed by flying an octocopter with a GPS module and a calibrated emitting antenna [8] over the antenna dish (Fig. 3) [5].

The raw data of this measurement showed a distinct mainlobe with a slight offset off the vertical direction (Fig. 4). A model for these data was derived by simulating the directivity of the antenna dish using the commercial software GRASP [9].

In order to form a twodimensional antenna pattern from the simulated onedimensional gain along the dipole axis of the feed antenna (Fig. 5), a rotational symmetry of the directivity was assumed. The absolute calibration was used to provide a direct measurement of the total gain of the receiver system, which was affected by small losses in the electronics. Furthermore since a deviation of the mainlobe from the vertical position was observed (Fig. 4), the actual direction of the mainlobe was also studied. To do both of this the **Friis-Equation** was applied to calculate the expected

FIGURE 3. Octocopter used for the calibration measurements with mounted calibrated emitting antenna and GPS module.

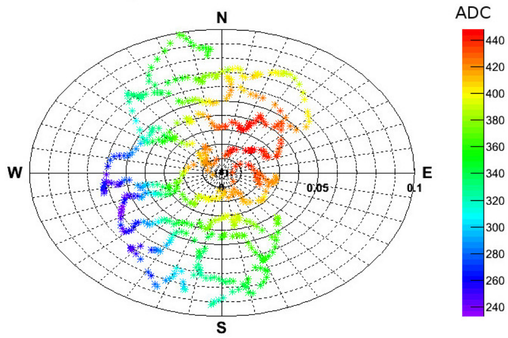

FIGURE 4. Raw data of a calibration flight: The mainlobe is slightly shifted from the vertical position. Large ADC values denote a high measured signal.

measured field strengths:

$$P_R = P_T + G_T + G_R + 20 \cdot log_{10}\left(\frac{\lambda}{4\pi d}\right). \tag{1}$$

It allows to calculate measured power at the antenna (P_R) using a calibrated emitting antenna (P_T and G_T known) in a specific distance in the far-field of the antenna (d) and the absolute gain of the receiver system (G_R). The receiver gain G_R was determined by fitting the calculated value to the calibration measurements. Furthermore the angular direction of the twodimensional directivity pattern was fitted to the measurements to find the direction of the antenna mainlobe.

Thus, a mainlobe zenith of $1.95° \pm 0.02°$ and a mainlobe azimuth of $34.34° \pm 0.51°$ were determined. An additional systematic uncertainty of the mainlobe position of $0.83°$ was derived from the uncertainties in the octocopter positions. The absolute gain of the receiver system was found to be $(26.45 \pm 0.03_{\mathrm{stat}} \pm 3.79_{\mathrm{syst}})\,\mathrm{dB}$.

SIGNAL SEARCH

Searching for signals from air showers, candidates with an expected large signal were selected, i.e. with energies above 10^{17} eV, a core position between 75 m and 150 m of the Antenna, zenith angles below $10°$ and a reconstructed shower axis which crossed the field of view of the antenna. This field of view was approximated as a cone in the determined direction of the main lobe, with the opening angle of the antenna mainlobe ($\approx 5°$).

The data of these signal candidates were cleaned of disturbances and a signal window of 5000 ns was scanned for strong peaks. No peak above the threshold of $5\,\sigma$ could be found. Since 1250 bins were analyzed in each of the 63 candidate traces, the significance of a single bin peak would be lowered additionally due to the large search window. A stacked analysis was performed by overlaying the signal candidate traces synchronized to the expected arrival time of the air shower at the antenna. In this analysis no peak above $3\,\sigma$ could be found (Fig. 6). Enhancing the statistics by loosening the cuts of the candidate selection did not provide a detection, either.

COMPARISON WITH MBR

For molecular bremsstrahlung a flux density of $I = 2.77 \cdot 10^{-24}\,\frac{\mathrm{W}}{\mathrm{m^2 Hz}}$ is expected for a shower with an energy of $3.36 \cdot 10^{17}$eV [1]. This was scaled to the distances of measured air showers using free-space path loss and to the energies of the signal candidates for linear and quadratic scaling of the signal with the given shower energy. The results were compared to the noise levels of the traces in units of equivalent field strengths. For both models of signal scaling with energy no detection would have been expected for the measured air showers (Fig. 7). Thus, no upper limit on the MBR-emission can be derived with the given data-set.

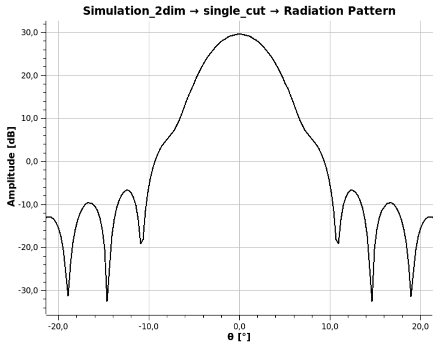

FIGURE 5. One-dimensional directivity cut from GRASP.

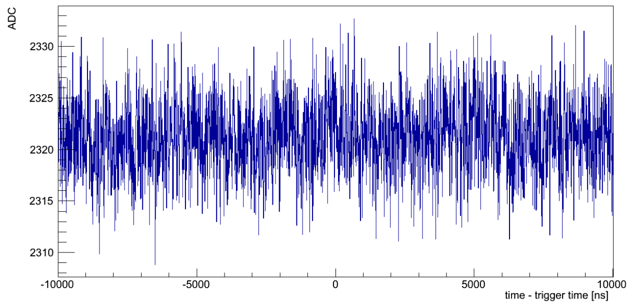

FIGURE 6. Stacked data traces of 9 signal candidates.

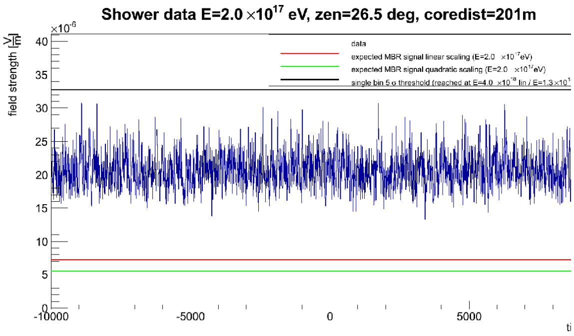

FIGURE 7. Comparison of a signal candidate with predictions from MBR.

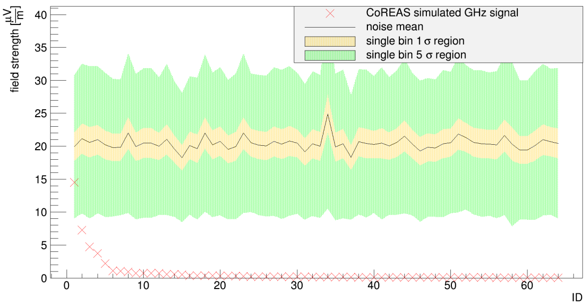

FIGURE 8. Comparison of the CoREAS simulations with the noise levels in the according traces.

COMPARISON WITH COREAS SIMULATIONS

To simulate emission mechanisms apart from molecular bremsstrahlung, the simulation code CoREAS [10][11] was used. For this simulation it were given as input parameters the relative position, energy and direction of the candidate air showers and the track length of the shower axis within the field of view of the antenna dish. A time constant of 2 ps and an unthinning constant of 10^{-7} was used. The output was a multifrequent radio signal which had to be reduced to a pure GHz signal. Therefore a Hanning window with the width of the bandpass of the receiver system was applied to the fourier transform of the output signal. The backward transform which was a pure GHz signal was rebinned to 4 ns bins to match the sampling frequency of the receiver system. The largest absolute value in the GHz signal of the polarization direction that was measured by the antenna gives the expected signal strength. All expected signals of the shower candidates were below the observation threshold (Fig. 8). Thus, no observation for the given data-set is expected.

CONCLUSION

The L-Band antenna of CROME is a receiver system to measure air showers using a radio signal in the GHz range. An absolute calibration for this system was performed using an octocopter with a mounted calibrated emitting antenna. No significant signal was detected in the effective 85 days of measuring time with the calibrated antenna setup. A comparison of the measured data with expected signals from Molecular Bremsstrahlung as well as simulations from CoREAS showed that the non-observation of a significant signal does not contradict the given expectations. In order to measure air showers, more measurement time (and thus higher energic air showers) or more amplification in the antenna system would have been needed. Measurements in the L-Band have shown to be largely affected by disturbances and thus difficult to use to find air shower signals.

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