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Precision measurements of the shower front of the radio emission in air showers with LOFAR

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High-energy cosmic rays impinging onto the atmosphere of the Earth initiate cascades of secondary particles: extensive air showers. The electrons and positrons in air showers interact with the geomagnetic field and emit radiation, which we record in the tens-of-MHz regime. The LOFAR radio telescope measures the radio emission with high antenna density and two polarization directions. We used LOFAR for measurements of the shape of the radio wave front of air showers with unprecedented precision with sub-nanosecond resolution. Our measurements show that the radio shower front is described best by a hyperboloid - it fits the data significantly better than the shapes discussed in the literature (conical and spherical shapes). We present recent results and show a quantitative comparison of different shapes analyzed. These results put strong constraints on the models to describe the radio emission in air showers. We also point out correlations between the shape of the shower front and the properties of the shower-inducing primary particle.

Primary author: HOERANDEL, Joerg (Radboud University Nijmegen)

Presenter: HOERANDEL, Joerg (Radboud University Nijmegen)

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