Geosynchrotron radio emission from cosmic ray air showers

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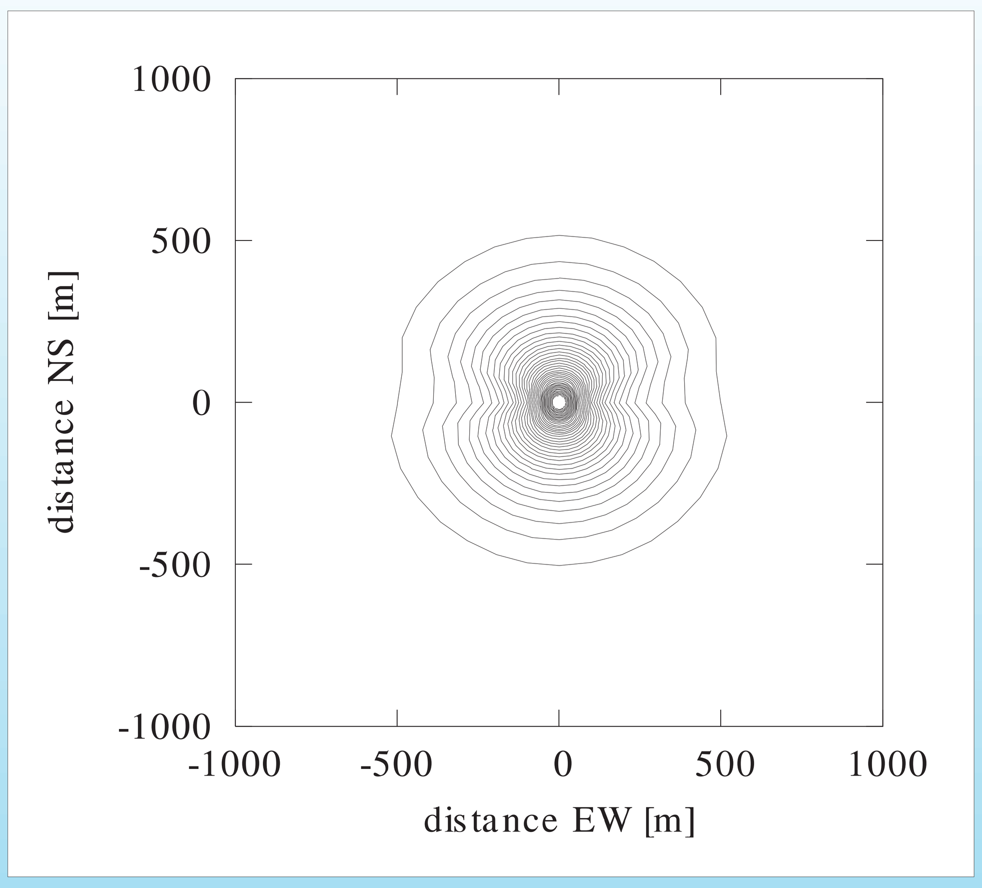
Abstract:

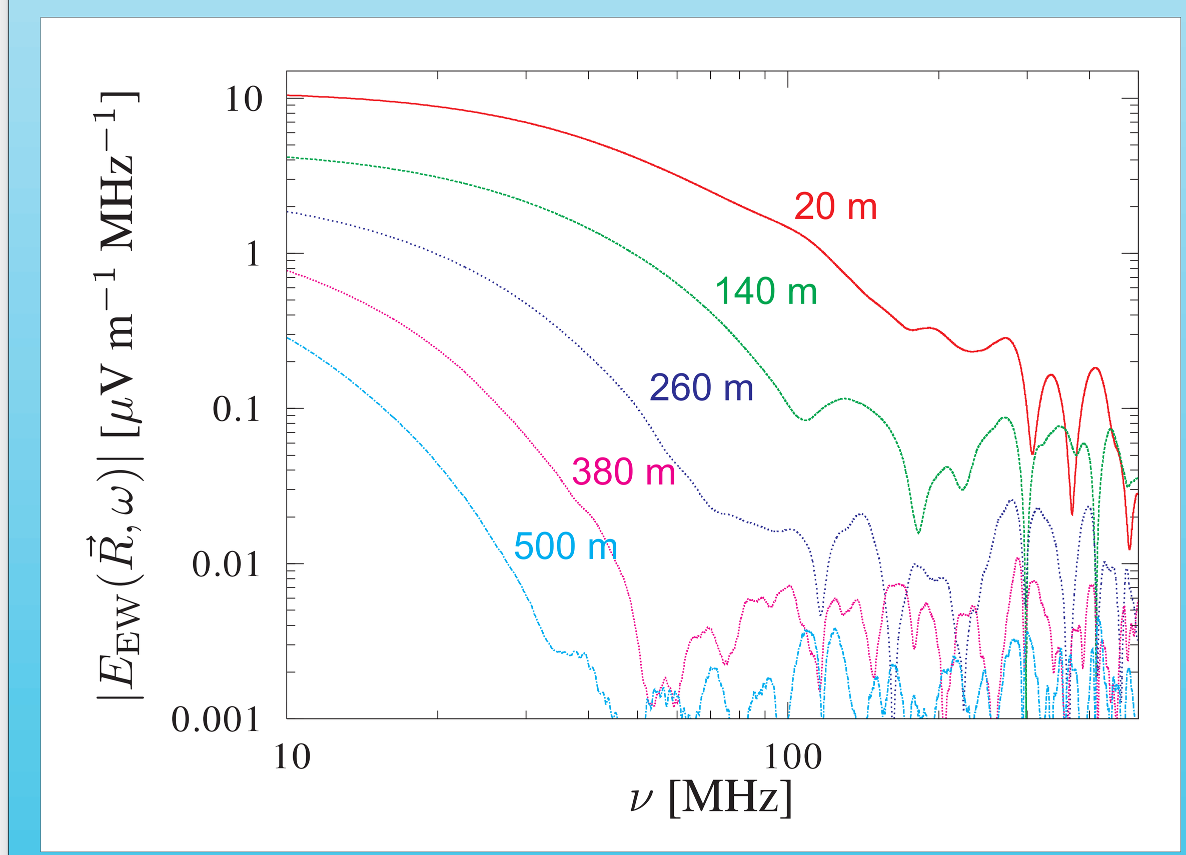
We have carried out simulations of radio emission from extensive air showers in the scheme of coherent geosynchrotron radiation arising from the deflection of electron-positron pairs in the earth's magnetic field. Having verified the consistency of our simulations with detailed comparisons of analytic calculations [1], Monte Carlo simulations [2] and historical data, we here present a subset of the results derived with our Monte Carlo model in [3]. Improvements of our simulation code making use of particle distributions generated with CORSIKA [4] additionally allow a first view on the radio emission's dependence on the nature of the primary particle [5].

Vertical Showers:



- total field strength emission pattern almost circular in spite of asymmetric emission mechanism
- weak north-south asymmetry present due to geomagnetic field inclination of 70° (typical for central Europe)

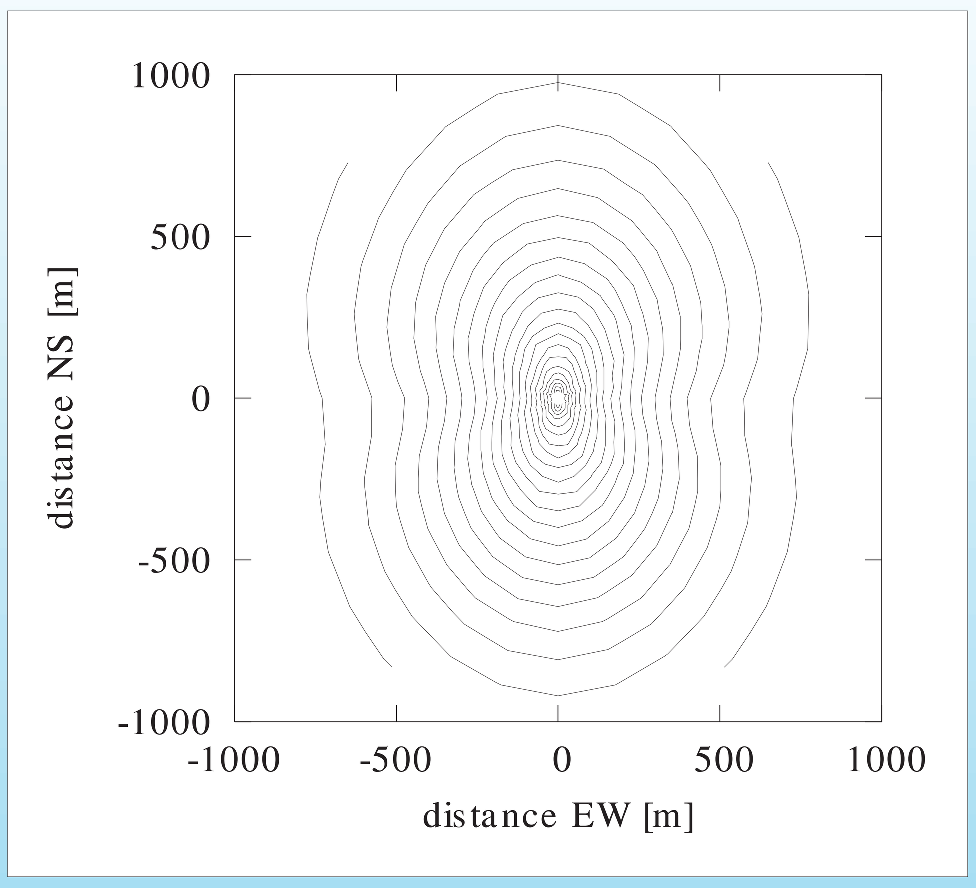
Fig. 1: Contour plot of 10 MHz total field strength emitted by a vertical 10^{17} eV air shower.



- steep decline with frequency due to coherence losses
- coherence better up to large distances at low frequencies
- strongly fluctuating field strength at high frequencies: incoherent regime (need better air shower model taking into account inhomogeneities in the air shower)

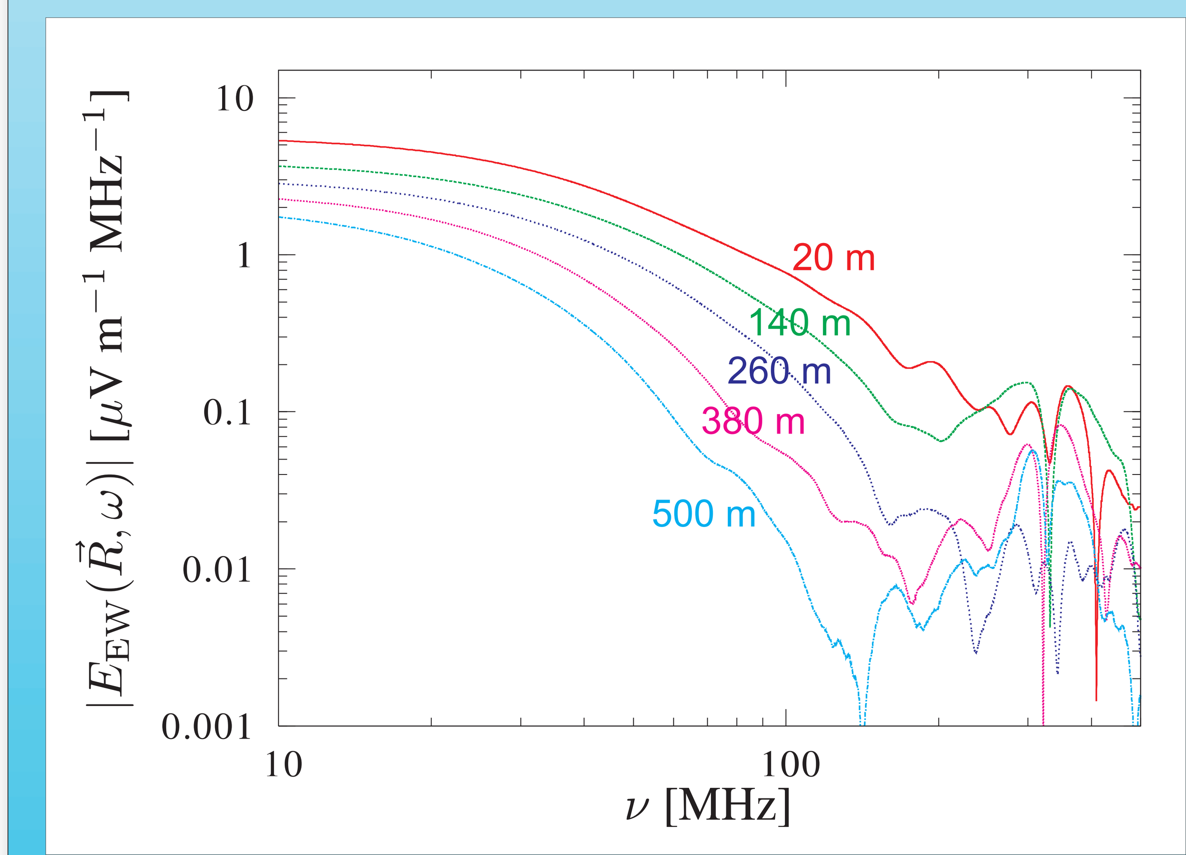
Fig. 2: Frequency spectra of radio emission from a vertical 10^{17} eV air shower at various distances from the shower centre.

Inclined Showers:



- pattern elongated along shower axis due to projection effects
- pattern broader as a whole due to larger observer distance to shower max.
- inclined showers better suited for radio detection

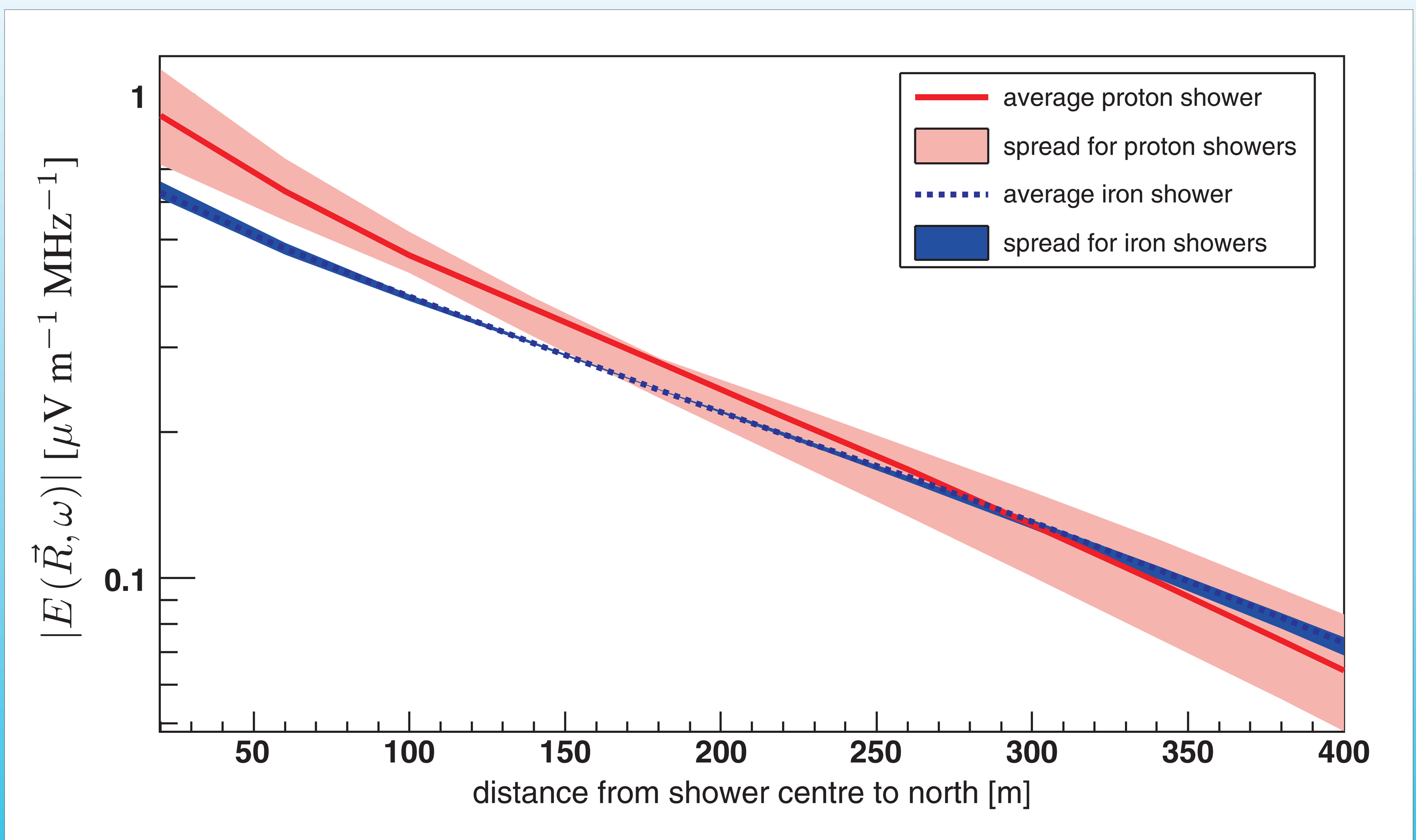
Fig. 3: Contour plot of 10 MHz total field strength emitted by a 45° inclined 10^{17} eV air shower coming from the south.



- much better coherence up to high frequencies even at large distances from the shower centre
- allows easier radio detection up to higher frequencies

Fig. 4: Frequency spectra of radio emission from a 45° inclined 10^{17} eV air shower at various distances from the shower centre.

Composition Dependence:



- the absolute value of the electric field strength scales directly with the shower's integrated electron-positron content
- the slope of the emission's lateral dependence is governed by the depth of the shower maximum
- together these effects lead to systematic differences in the emission pattern for proton- and iron-induced showers, which can possibly be exploited for composition analyses with radio measurements
- the shower-to-shower fluctuations are much more significant for proton- than for iron-induced showers (explainable by the superposition model)
- there seems to be a specific distance (in this case ~150 m), where the total field strength is very much independent of shower-to-shower fluctuations, except in extreme cases (included in the spread for proton showers shown here)
- this analysis has to be repeated at higher energies, with better statistics and for various zenith angles and azimuthal directions

Fig. 5: Lateral dependence of the 10 MHz total field strength emission from average vertical 10^{16} eV air showers induced by proton and iron primaries, respectively. The shaded bands indicate the spread arising from shower-to-shower fluctuations.

Conclusions:

- first time realistic modelling of radio emission from EAS
- results relate radio emission features to shower parameters
- inclined air showers particularly suitable for radio observations
- improved model based on CORSIKA allows analysis of composition effects
- nature of the primary particle has systematic influence on emission
- much more realistic CORSIKA-based simulations currently being performed

References:

[1] T. Huege, H. Falcke, Astronomy & Astrophysics 412, 19 (2003)
[2] T. Huege, H. Falcke, Astronomy & Astrophysics 430, 779 (2005)
[3] T. Huege, H. Falcke, Astroparticle Physics 24, 116 (2005)
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[5] T. Huege et al. - LOPES collaboration, Proc. 29th ICRC, Pune, India (2005)