Geosynchrotron radio emission
from extensive air showers

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Radio emission from EAS

- historical works were not detailed enough for application to LOPES
- refractive index of atmosphere \( \sim 1.0 \)
  - geomagnetic mechanism favoured over Askaryan-type Cherenkov radiation
- approach: geosynchrotron emission
  - electron-positron pairs gyrating in the earth’s magnetic field: radio pulses
  - coherent emission at low frequencies
- first step: analytic calculations
- second step: Monte Carlo simulations based on analytically parametrised air showers
- current work: Monte Carlo simulations based on CORSIKA-simulated air showers
The Monte Carlo code

- time-domain MC
- no far-field approximations
- full polarisation info
- thoroughly tested
- compared with analytics and data
- takes into account:
  - longitudinal & lateral particle distributions
  - particle track length & energy distributions
  - air shower and magnetic field geometry
  - shower evolution as a whole
Monte Carlo, analytics and data

- vertical $10^{17}$ eV shower
- good agreement in spite of very different methods
Spectra of a vertical shower

- Spectra steeper at higher distances
- 55 MHz: coherence only up to ~300 m (vertical showers)
- 10 MHz: very coherent

Incoherent regime:
Need better air shower model (inhomogeneities, pitch angles)
A vertical air shower at 10 MHz

Total field strength pattern of a vertical $10^{17}$ eV shower:

- total field strength emission pattern highly symmetrical in spite of intrinsic asymmetry introduced by geomagnetic field
- only small effect of geomagnetic field inclination on total emission
Inclined air showers

- projection effects along the shower axis, but:
- pattern gets broader as a whole (distance to shower max)!
Coherence for inclined showers

- peak emission levels slightly lower, but:
- coherence up to much higher distances
Linear polarisation

- 45° zenith angle, shower along north-south direction
- 45° zenith angle, shower along east-west direction

most power in polarisation direction perpendicular to B-field and shower axes
Scaling with CR energy

For 10 MHz, nearly linear scaling is observed, with the scaling flatter at higher distances.
The improved code

- simulate air showers with CORSIKA
- write out relevant particle distributions (pitch angle, energy, spatial, ...) in histograms
- from these histograms, reconstruct particle distributions in our radio emission Monte Carlo simulations
- allows many new analyses, here:
  - influence of shower-to-shower fluctuations and primary particle type on radio emission
Variance of the radio signal

- systematic differences between different primaries
  - lateral slope of radio signal
  - overall amplitude
- need more detailed analysis to assess potential for composition studies with radio measurements

$10^{16}$ eV, 10 MHz

$|E(R, 2\pi\nu)| / [\mu V m^{-1} MHz^{-1}]$

Distance from shower centre to north [m]
Conclusions

- performed realistic modelling of radio emission from EAS for the first time
- currently implementing improved Monte Carlo simulations based on CORSIKA
- made a first step towards composition studies with radio measurements
- LOPES10 results support the geosynchrotron mechanism
- made many detailed predictions, to be verified with LOPES30
- LOFAR will be a great tool for study of CRs