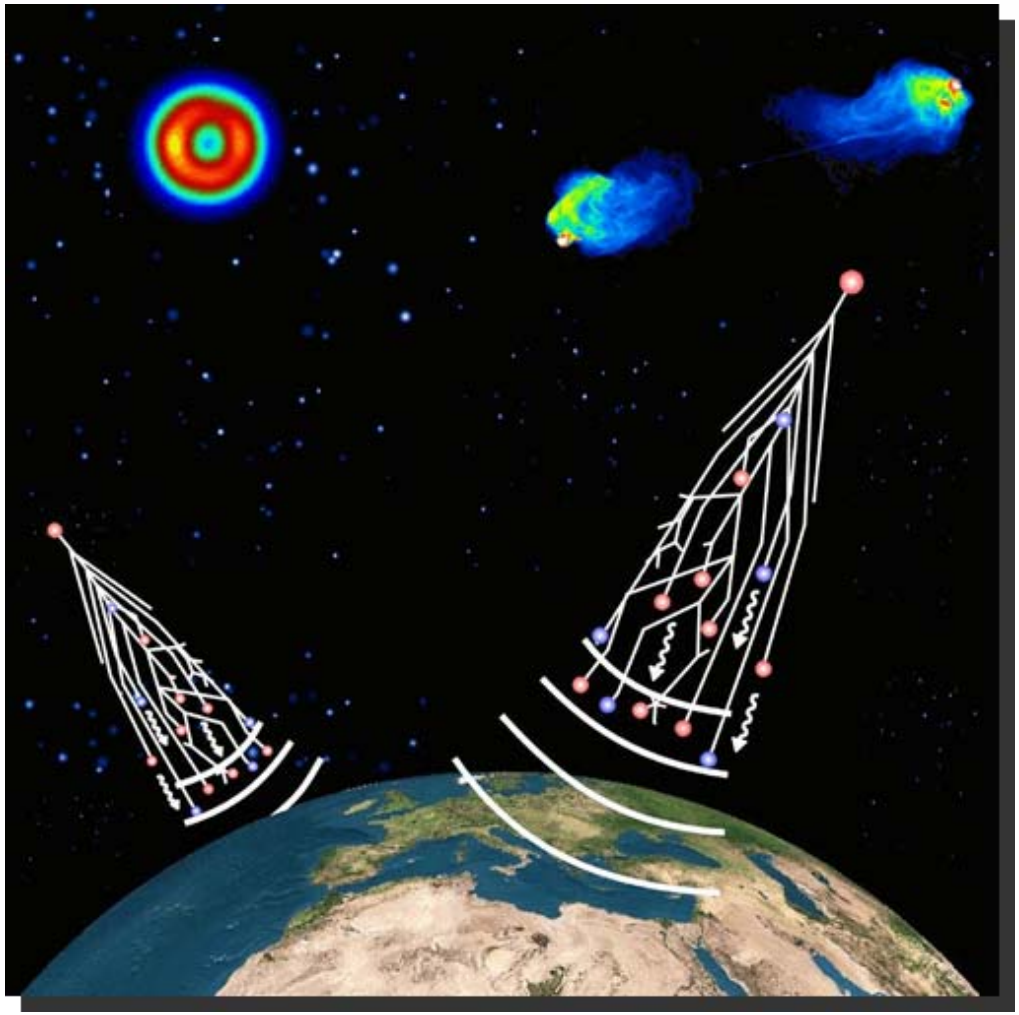
Geosynchrotron radio emission from extensive air showers



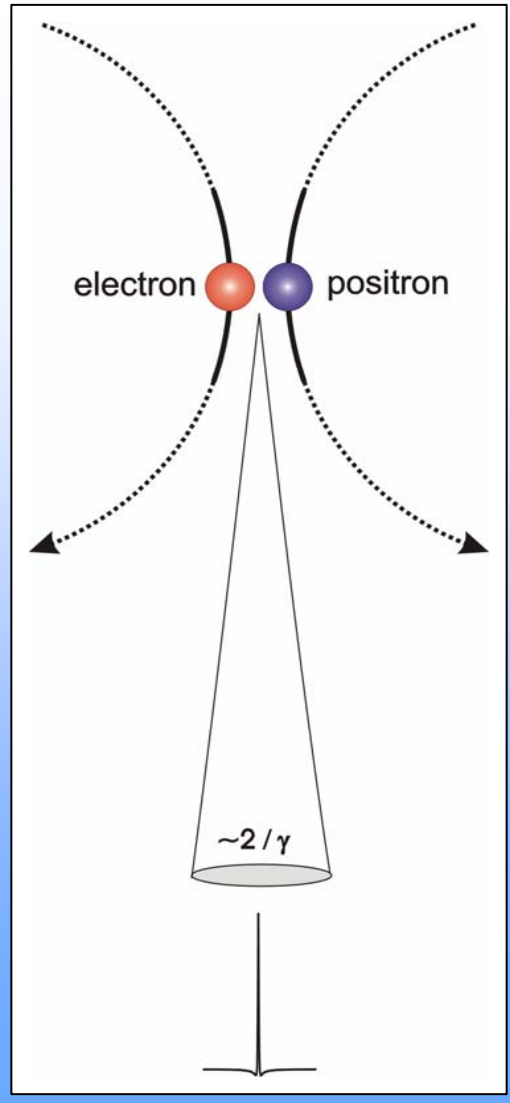
Tim Huege for the LOPES collaboration

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

AG-Tagung Köln, 29.09.2005

Radio emission from EAS

- historical works were not detailed enough for application to LOPES
- refractive index of atmosphere ~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



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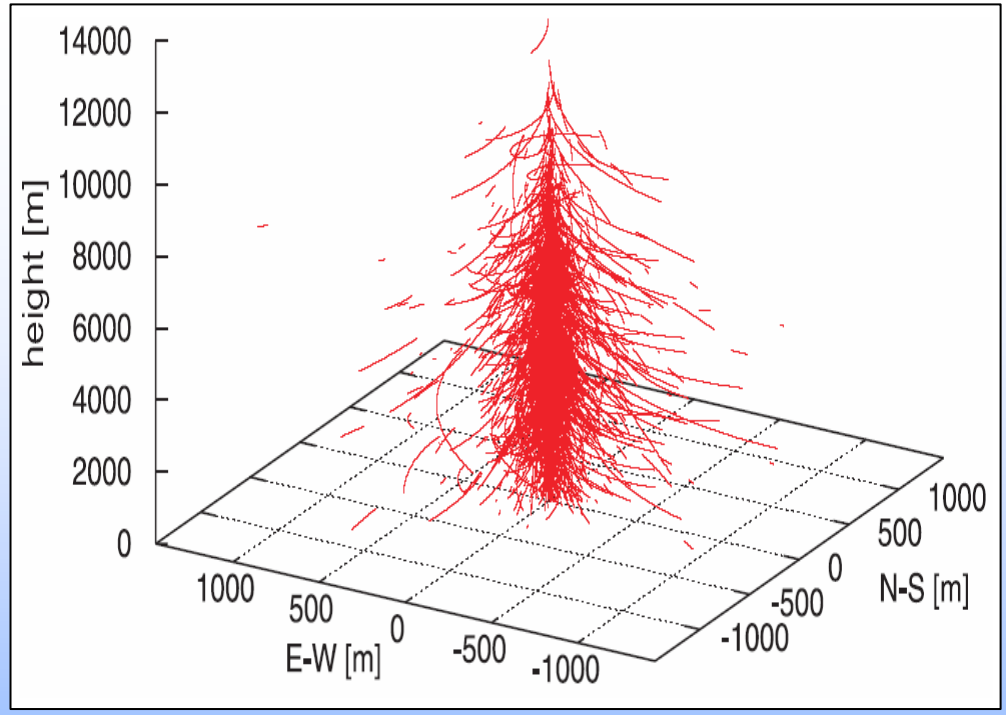
The Monte Carlo code

- 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



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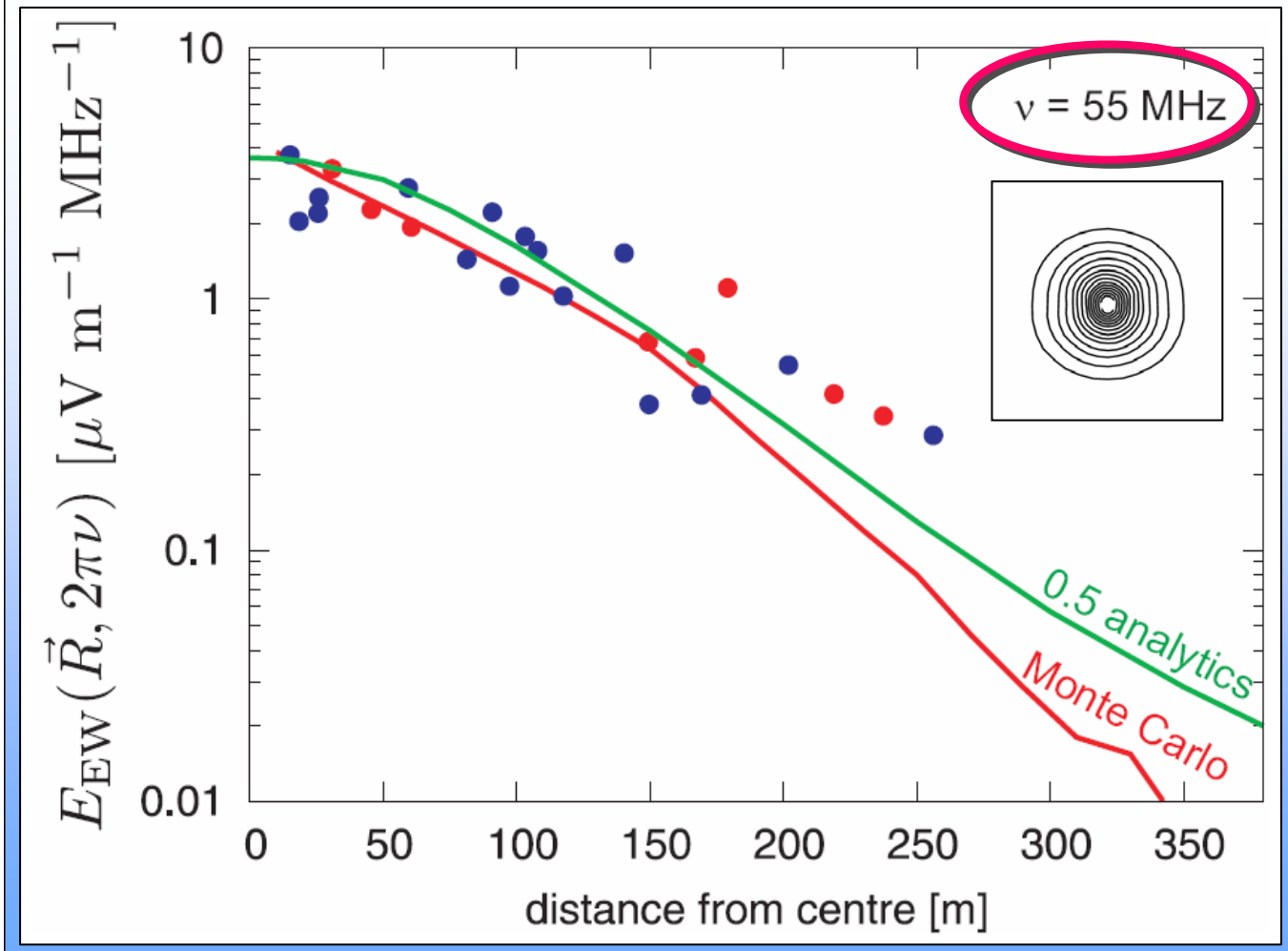
Monte Carlo, analytics and data



- vertical 10^{17} eV shower
- good agree-ment in spite of very different methods

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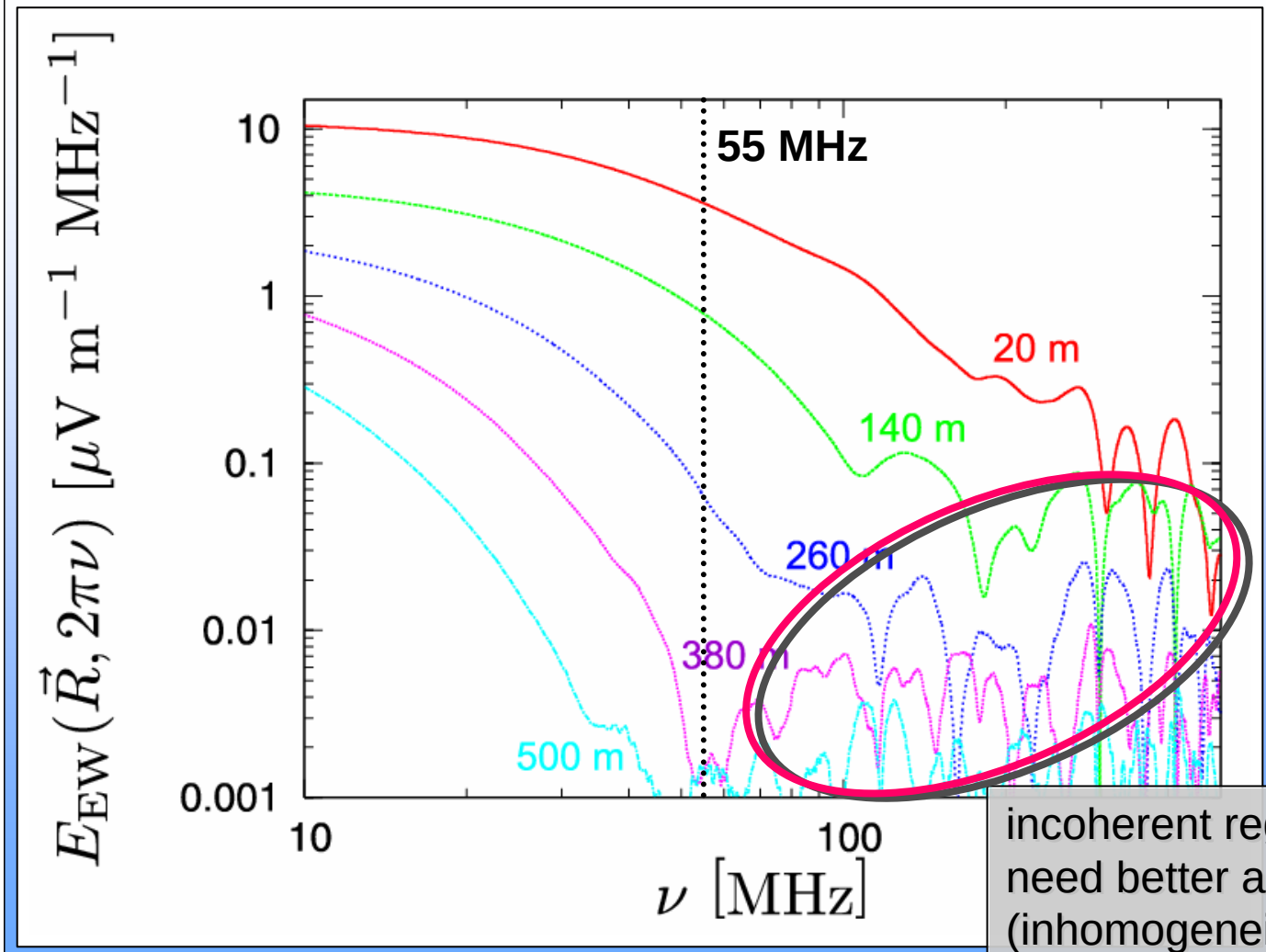
Spectra of a vertical shower



- 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)

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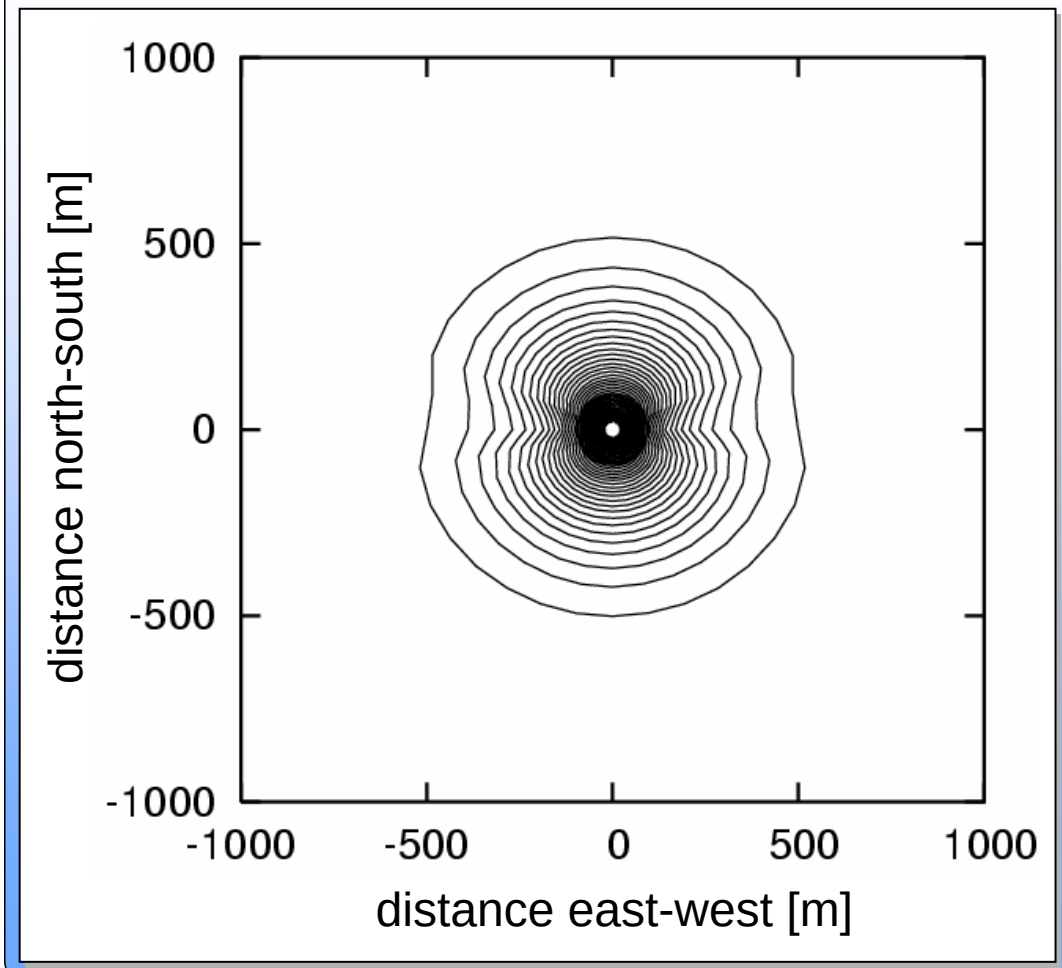
A vertical air shower at 10 MHz

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

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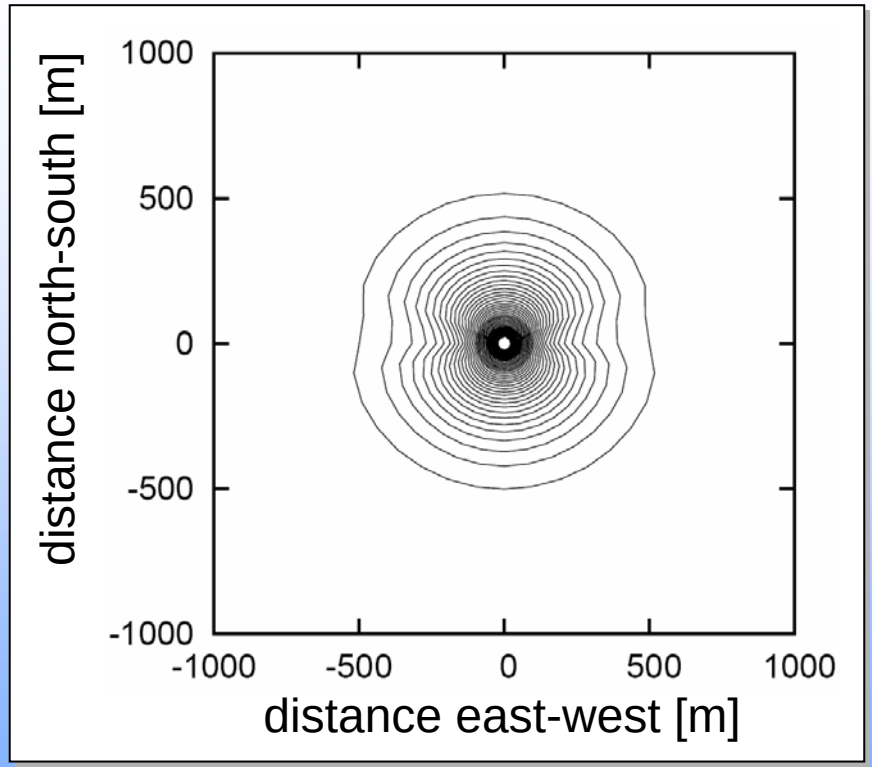
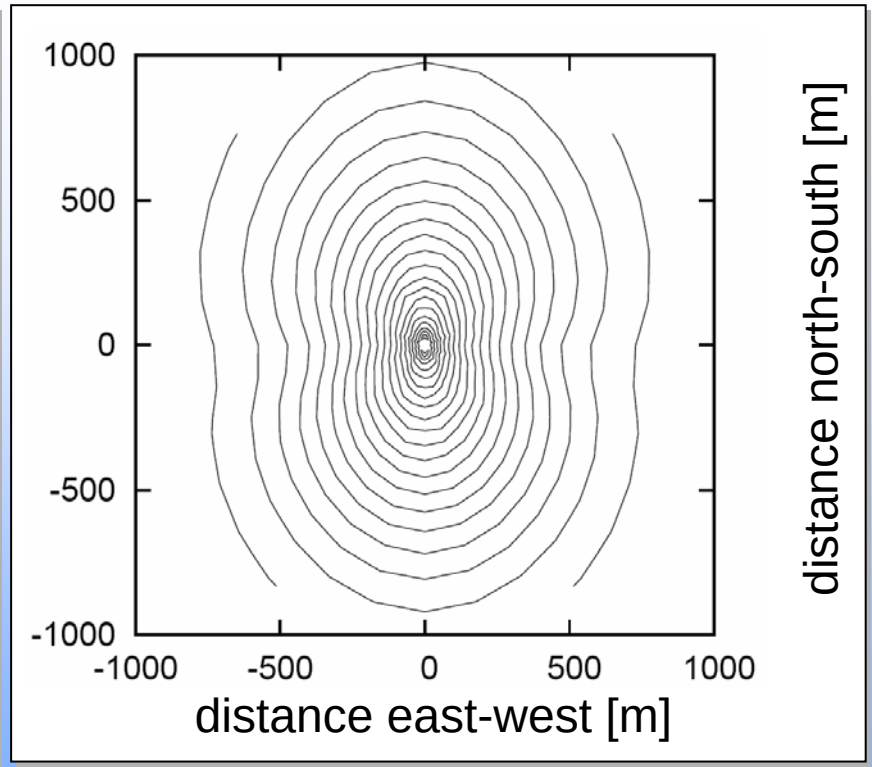
Inclined air showers

Vertical 10^{17} eV shower



45° inclined 10^{17} eV shower



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

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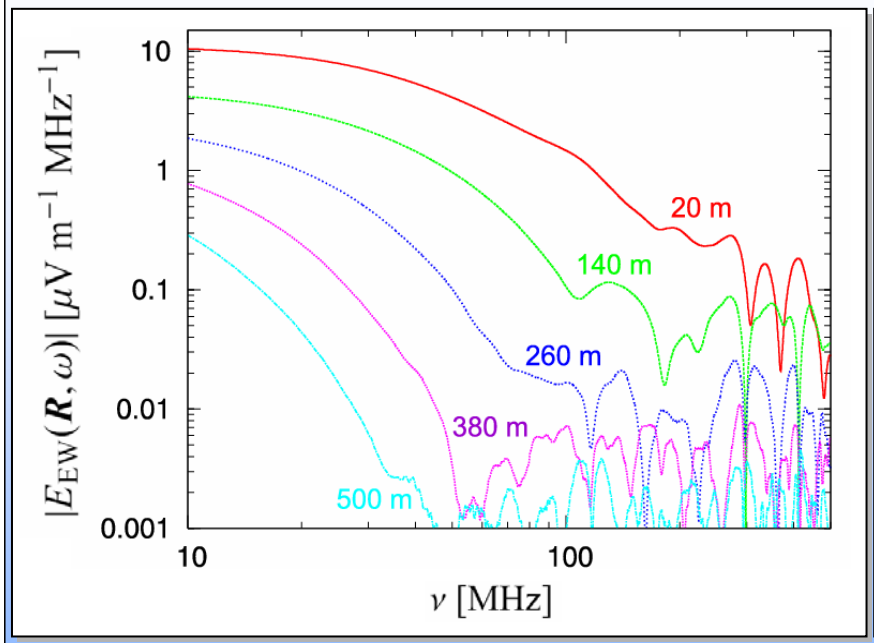
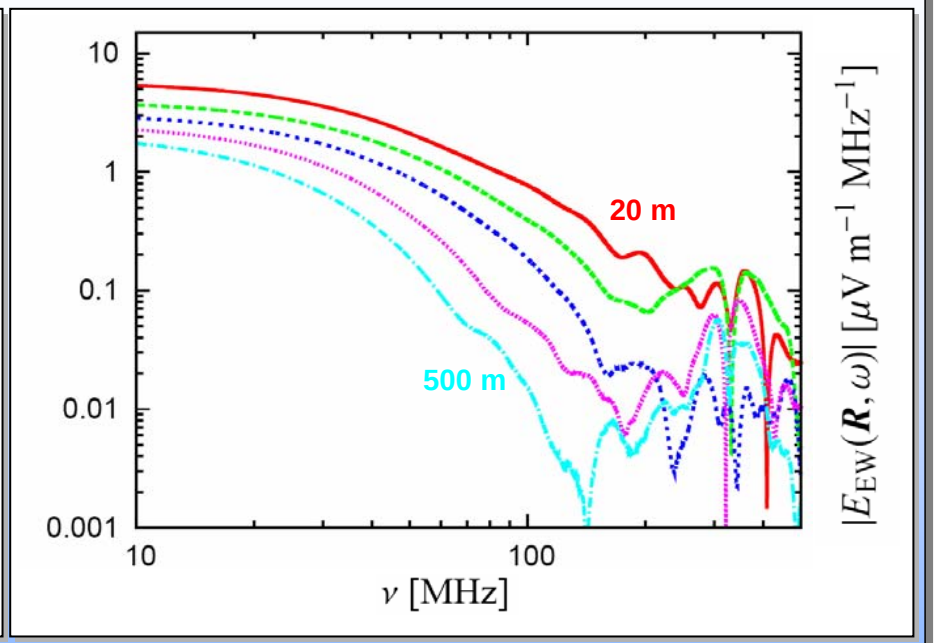
Coherence for inclined showers

Vertical 10^{17} eV shower



45° inclined 10^{17} eV shower



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

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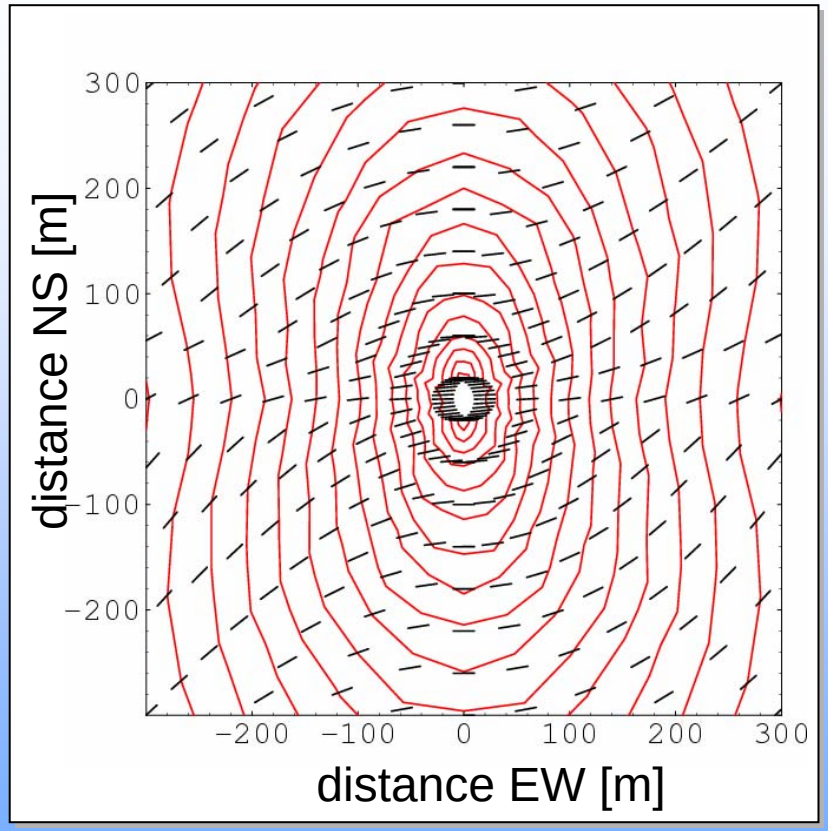
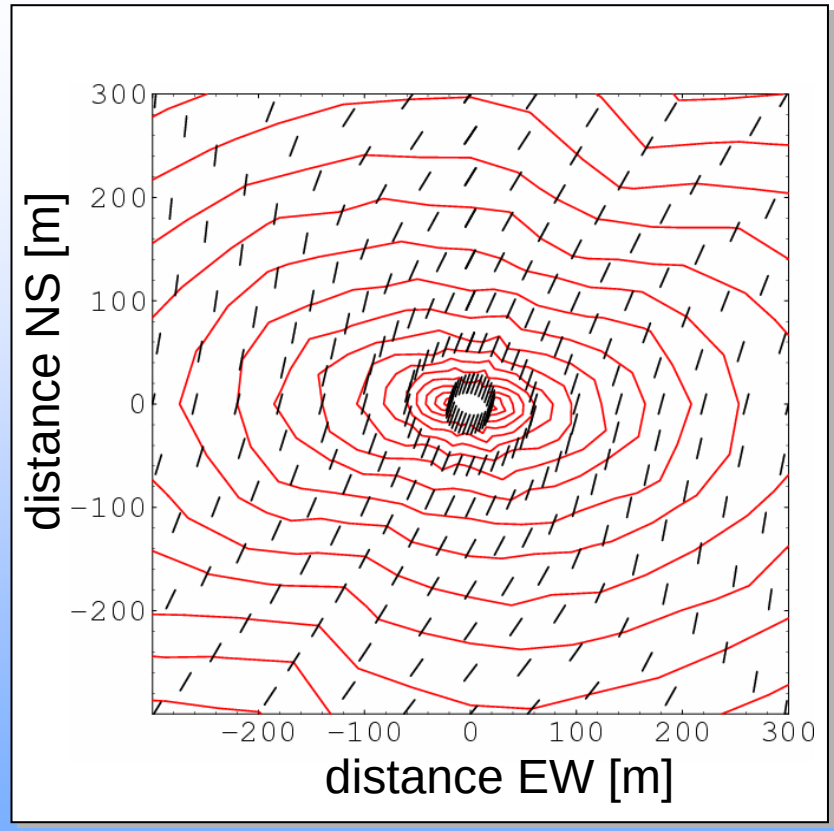
Linear polarisation

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

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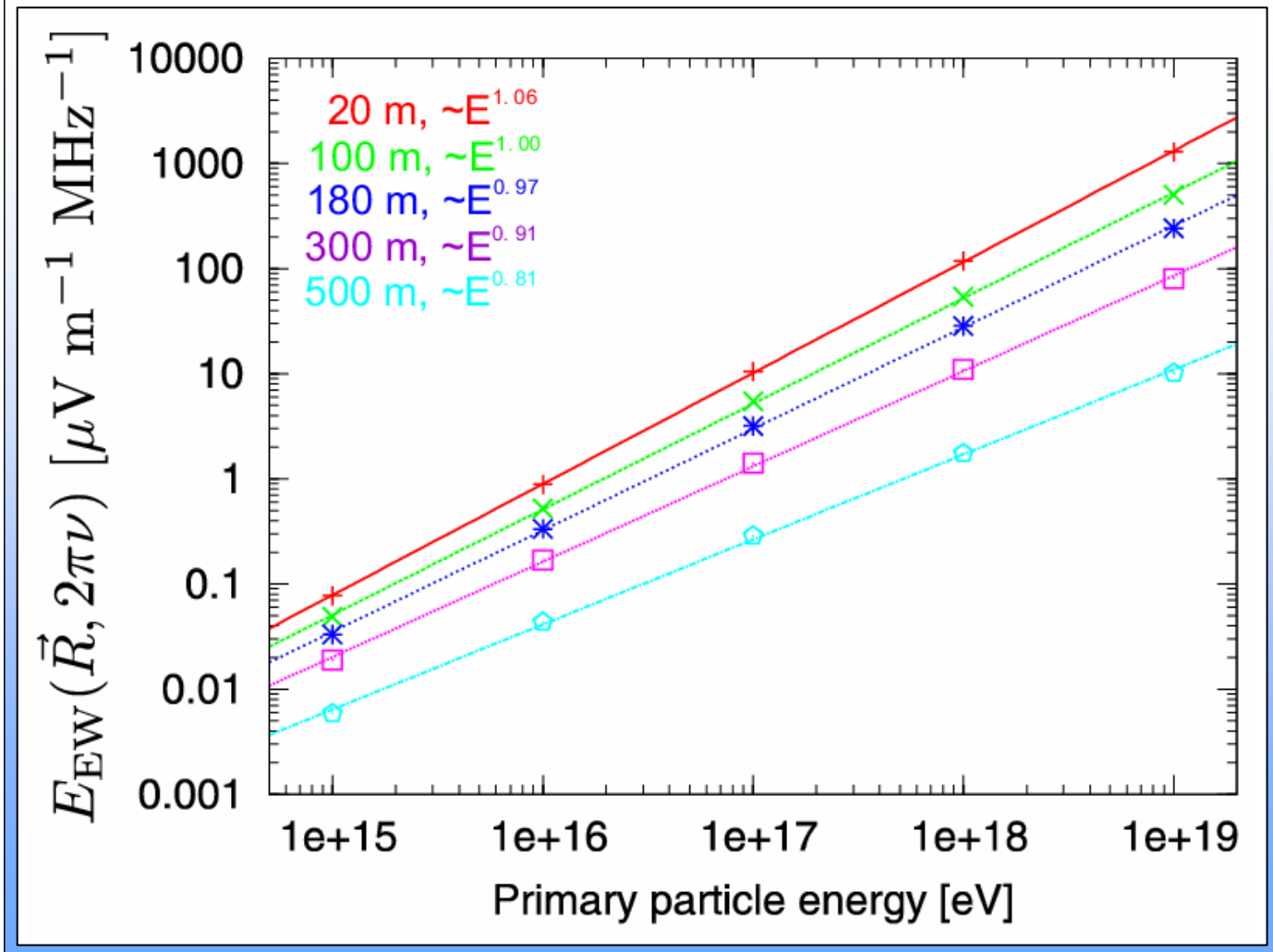
Scaling with CR energy



- for 10 MHz
- nearly linear scaling
- flatter at higher distances

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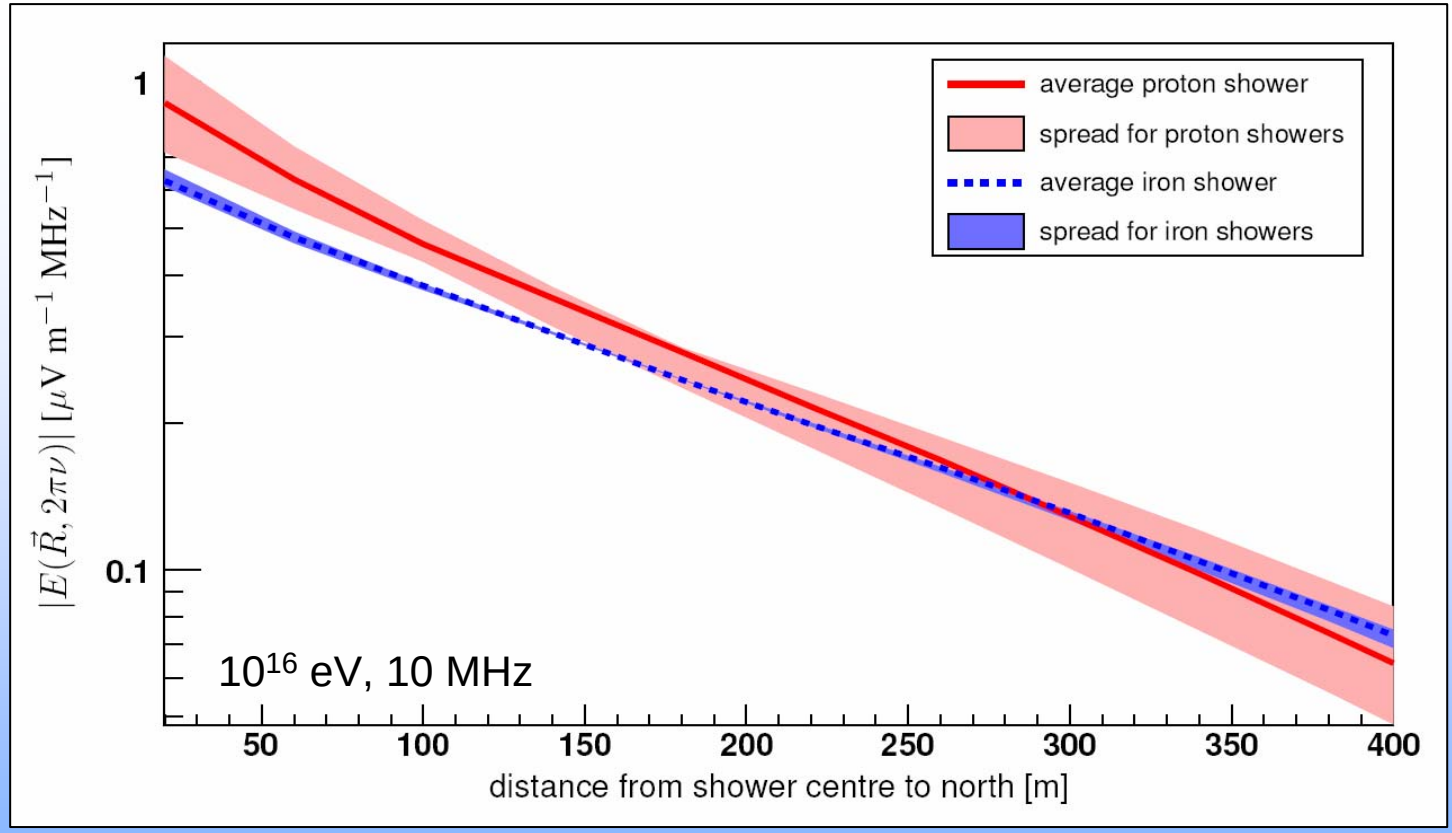
The improved code

- 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

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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