Simulation of radio signals from 1-10 TeV air showers using EGSnrc

N. N. Kalmykov [1], A. A. Konstantinov [1], R. Engel [2]

[1] *Skobeltsyn Institute of Nuclear Physics, Moscow State University*
[2] *Forschungszentrum Karlsruhe, Institut fuer Kernphysik*

Common model acceptations

Using track-by-track technique for calculation
of electric field
(i.e. summation of electric fields produced
by all particles on each their track)

Fraunhofer approximation: $\Delta L << R$ & $\lambda << R$,
ΔL – particle track length
R – observation distance
λ – radiation wavelength

And thus Far-field approximation:
only radiation term, i.e. $\sim 1/R$ terms considered

Calculation scheme up to now limited to
low energies (100 TeV)

Air shower simulation

EGSnrc for Monte Carlo simulation of
electromagnetic showers
(photons, electrons and positrons)

US standard atmosphere
(200 slabs of constant density)

Earth's magnetic field for Karlsruhe location

Primary particle: photon (1 - 10 TeV)

Vertical showers ($\theta = 0°$) with a start height
at 30 km

Low-energy thresholds: 100 keV, 1MeV

No thinning or importance sampling

Radio emission mechanisms adopted

We take into account geosynchrotron
and Cherenkov radiation

For a charged particle moving both in a magnetic field $\mathbf{B}$ and through medium with r.c. n we consider an electric field vector $\mathbf{E}$ as the sum of two parts with the special properties:

$$\mathbf{E} = \mathbf{E}^{(1)} + \mathbf{E}^{(2)}$$

$$\mathbf{E}^{(1)} \rightarrow \mathbf{0} \quad \text{when} \quad |\mathbf{B}| \rightarrow 0$$
$$\mathbf{E}^{(2)} \rightarrow \mathbf{0} \quad \text{when} \quad n \rightarrow +1$$

$\mathbf{E}^{(1)}$ is the electric field due to Earth's magnetic field:
(geosynchrotron radiation)

$\mathbf{E}^{(2)}$ is the electric field due to medium properties:
(Cherenkov radiation)

Charge excess

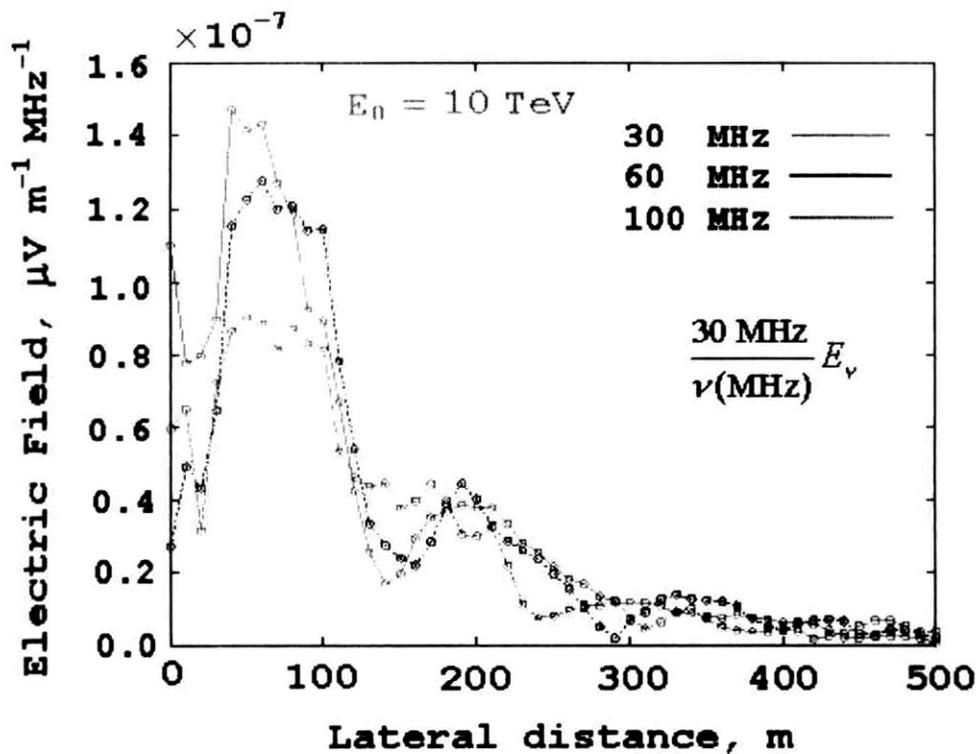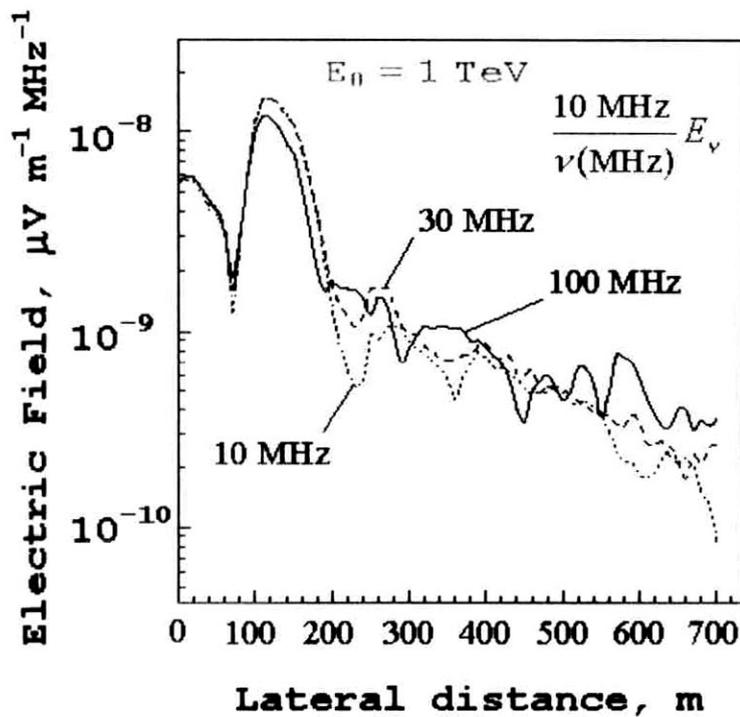Charge excess at shower maximum:
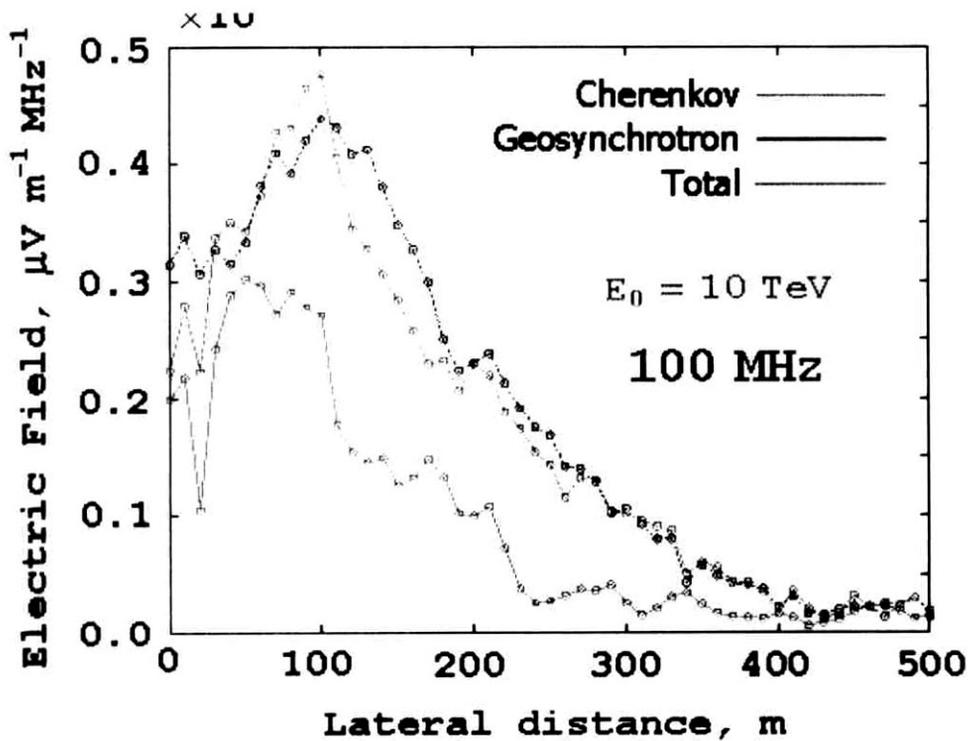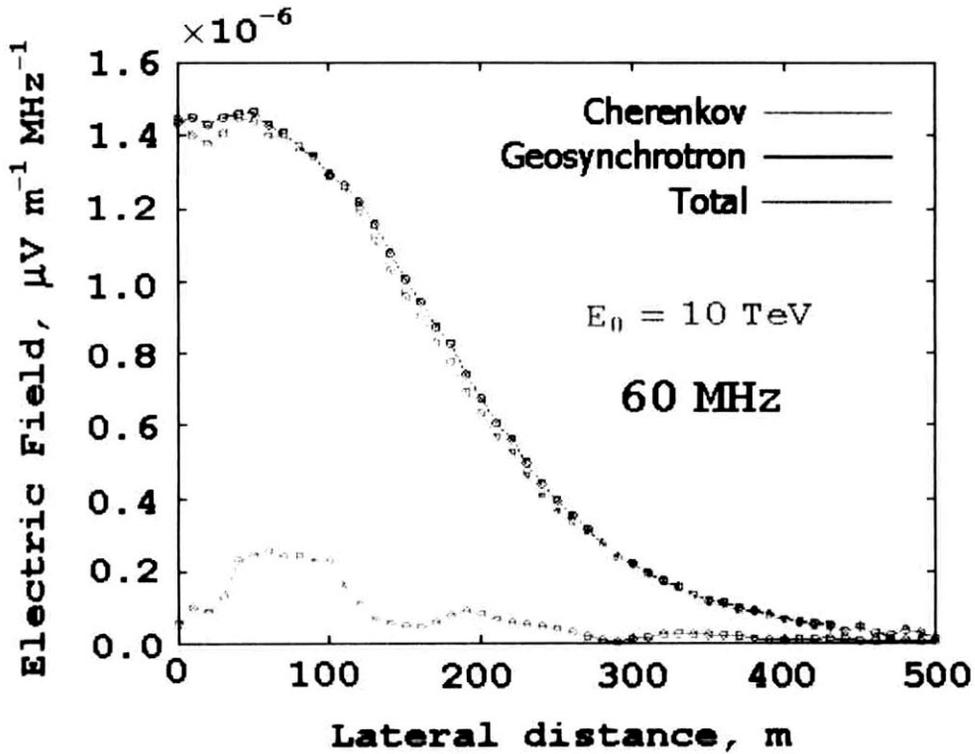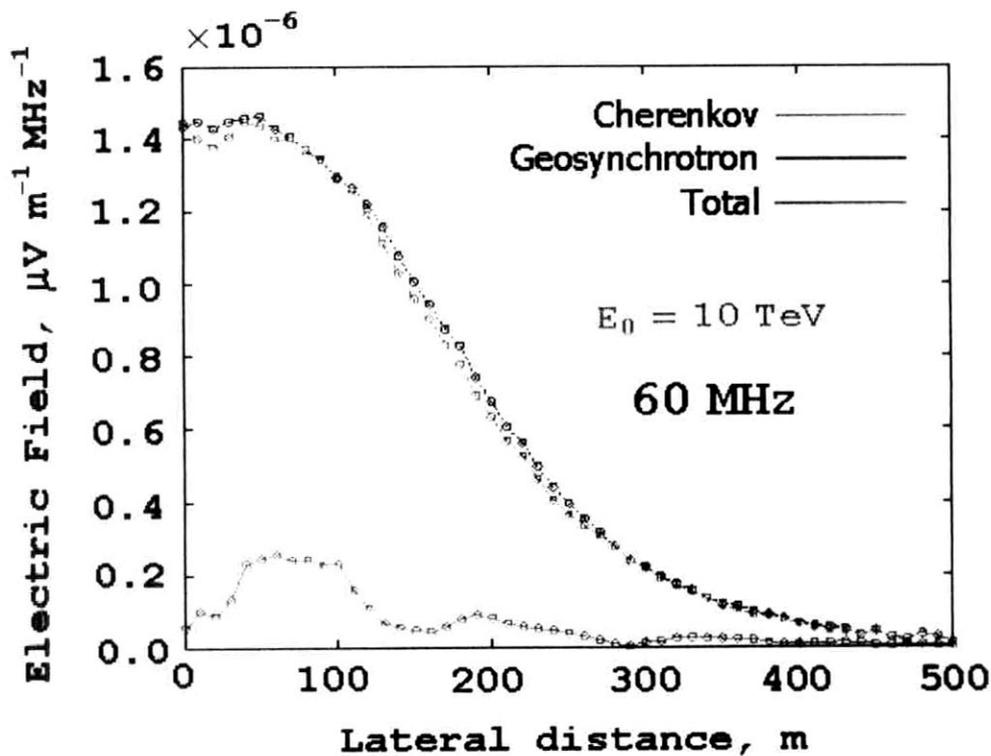
~ 20% for E_{thr} = 1 MeV
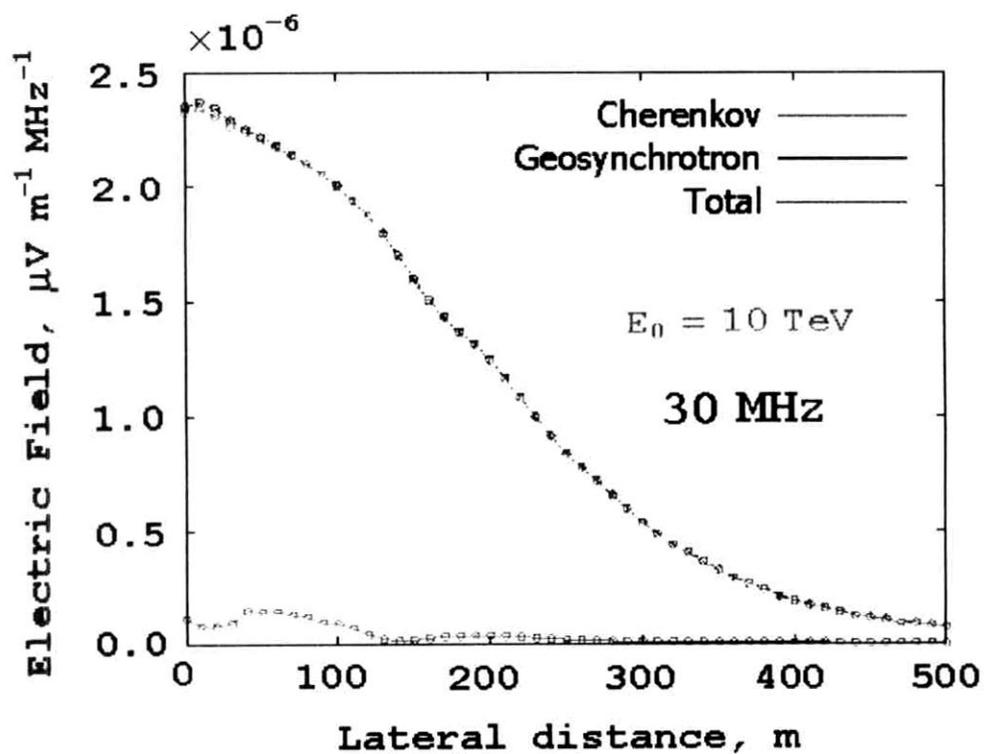
~ 7% for E_{thr} = E_{cher} (> 21 MeV)
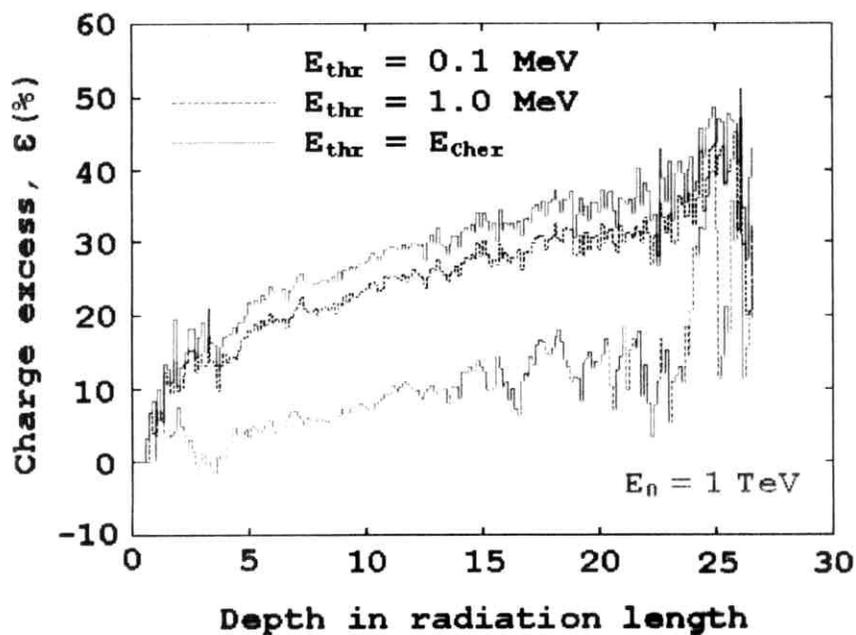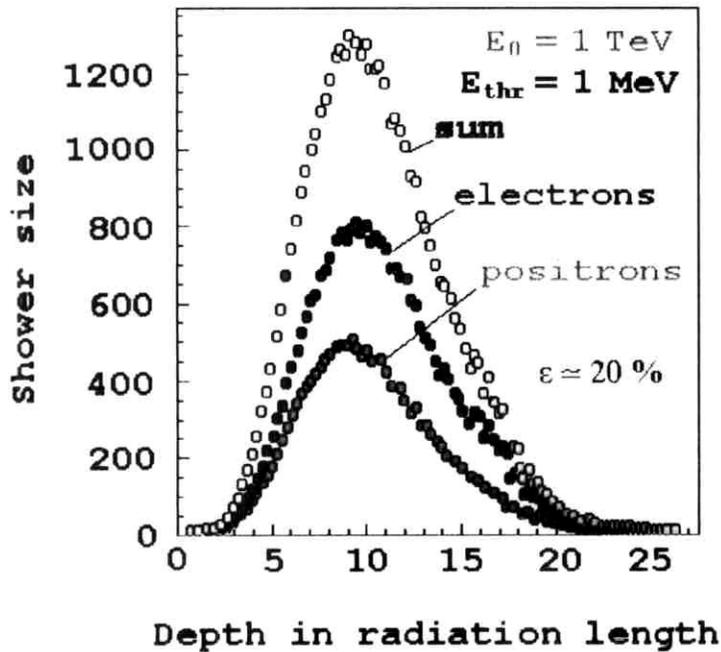
Coordinate system
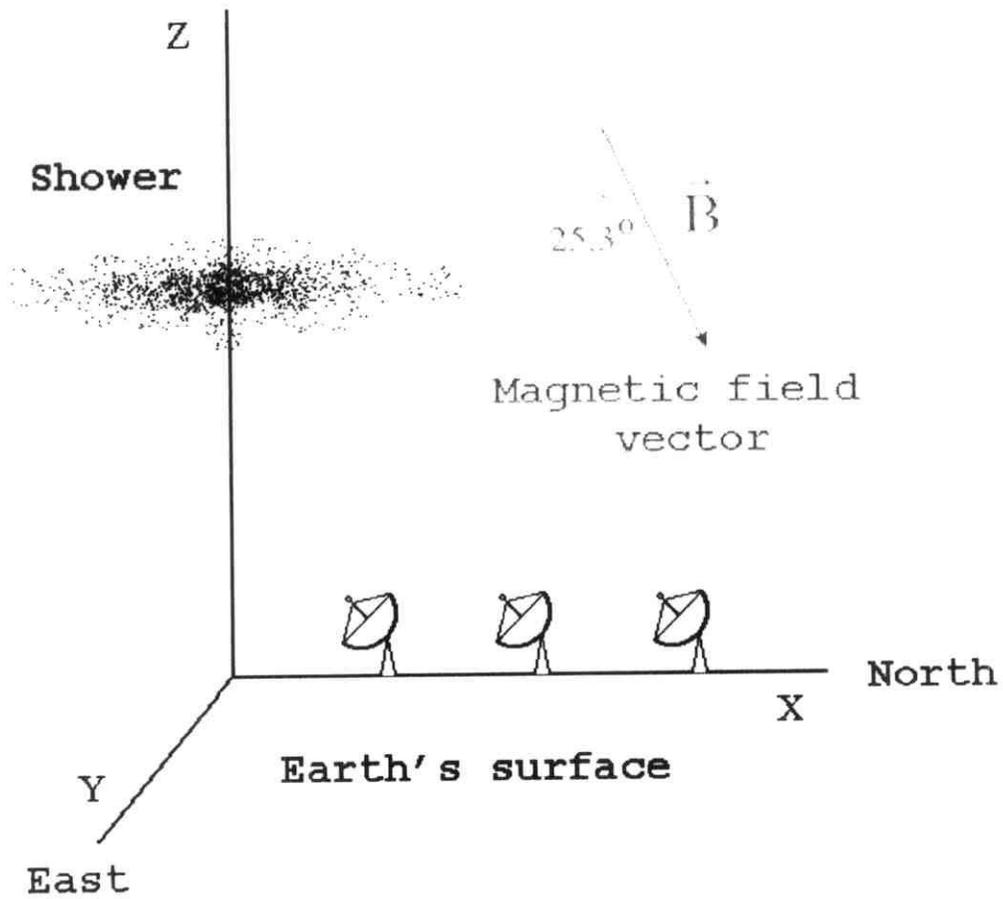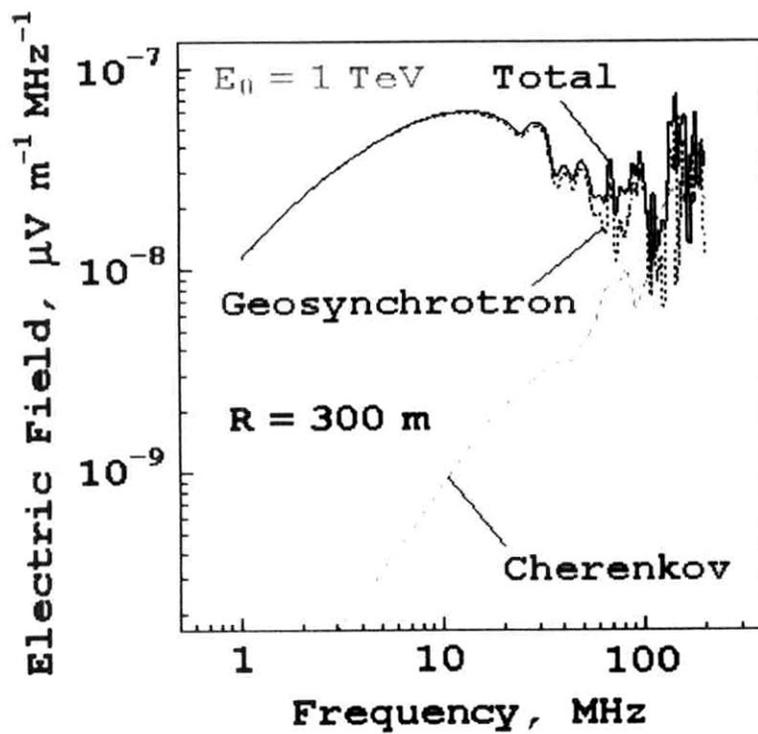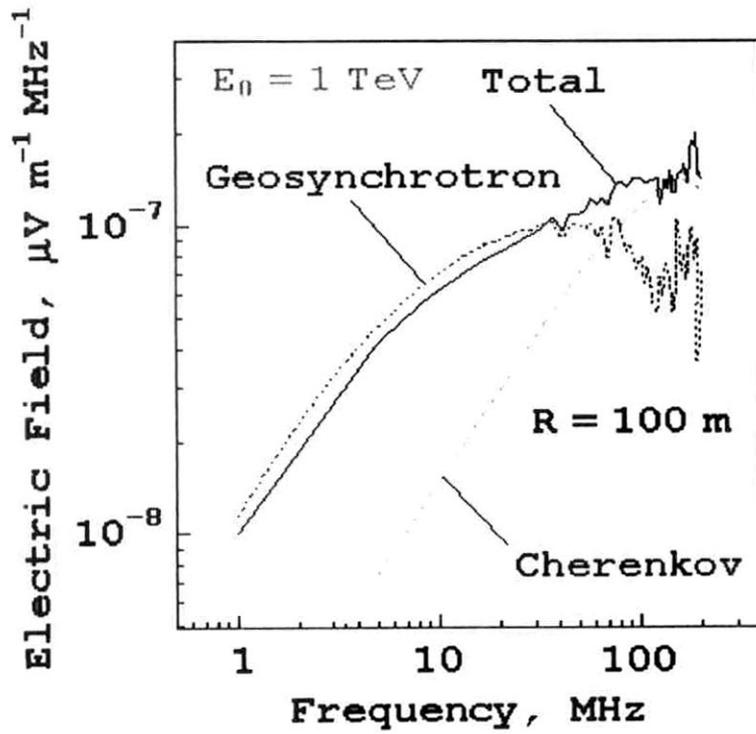
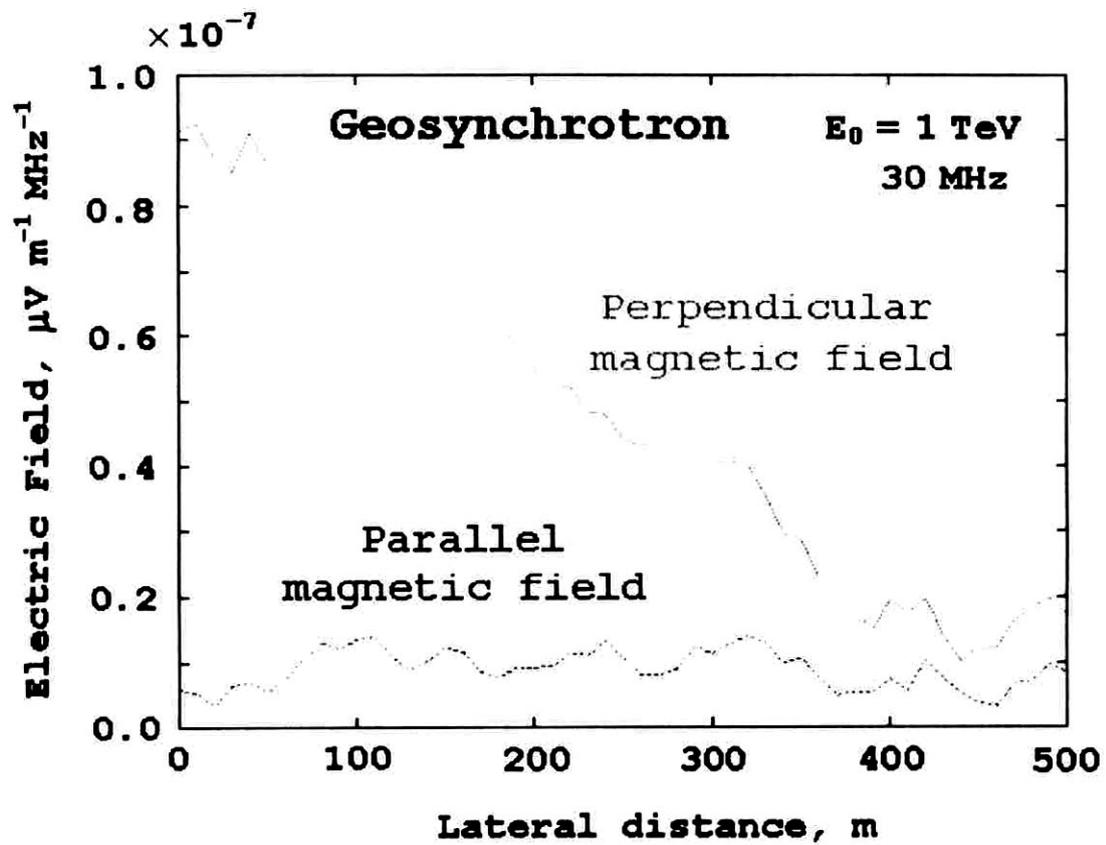# Cherenkov radio emission

Total radio signal at 60 and 100 MHz

Total radio signal at 30 and 60 MHz

Frequency spectrum

Magnetic field dependence
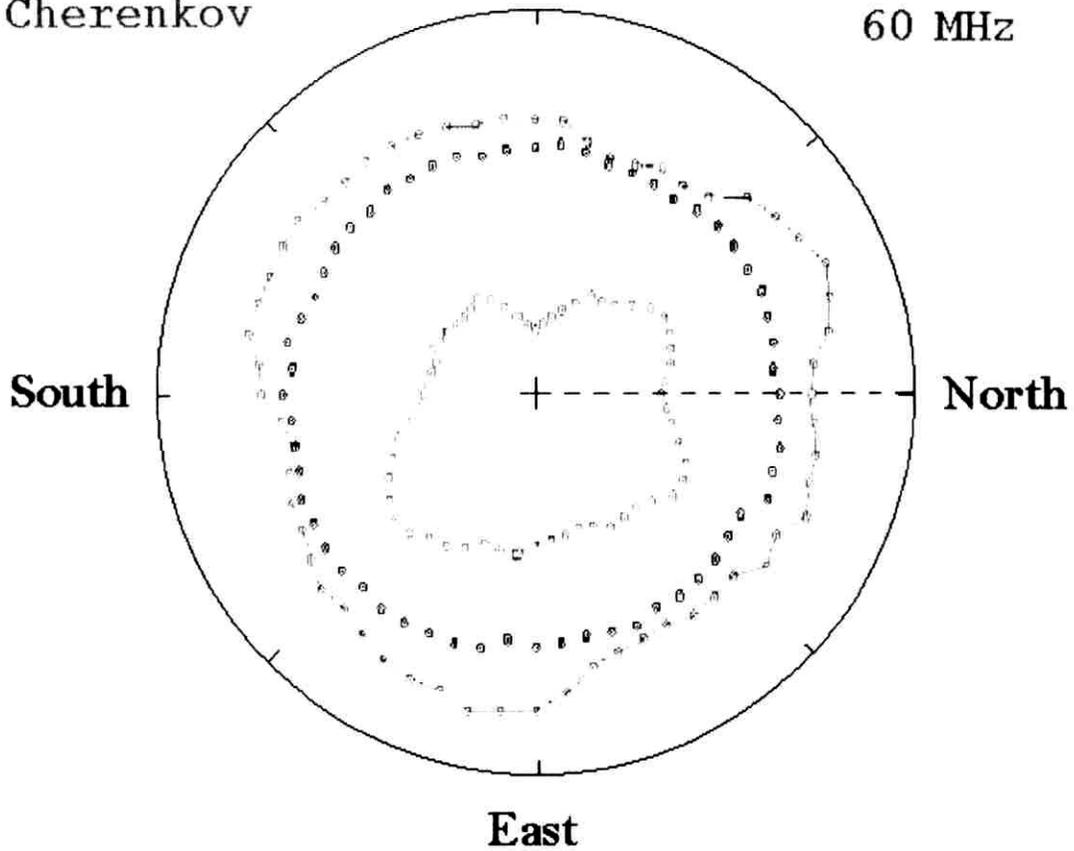
Azimuth dependence (2)
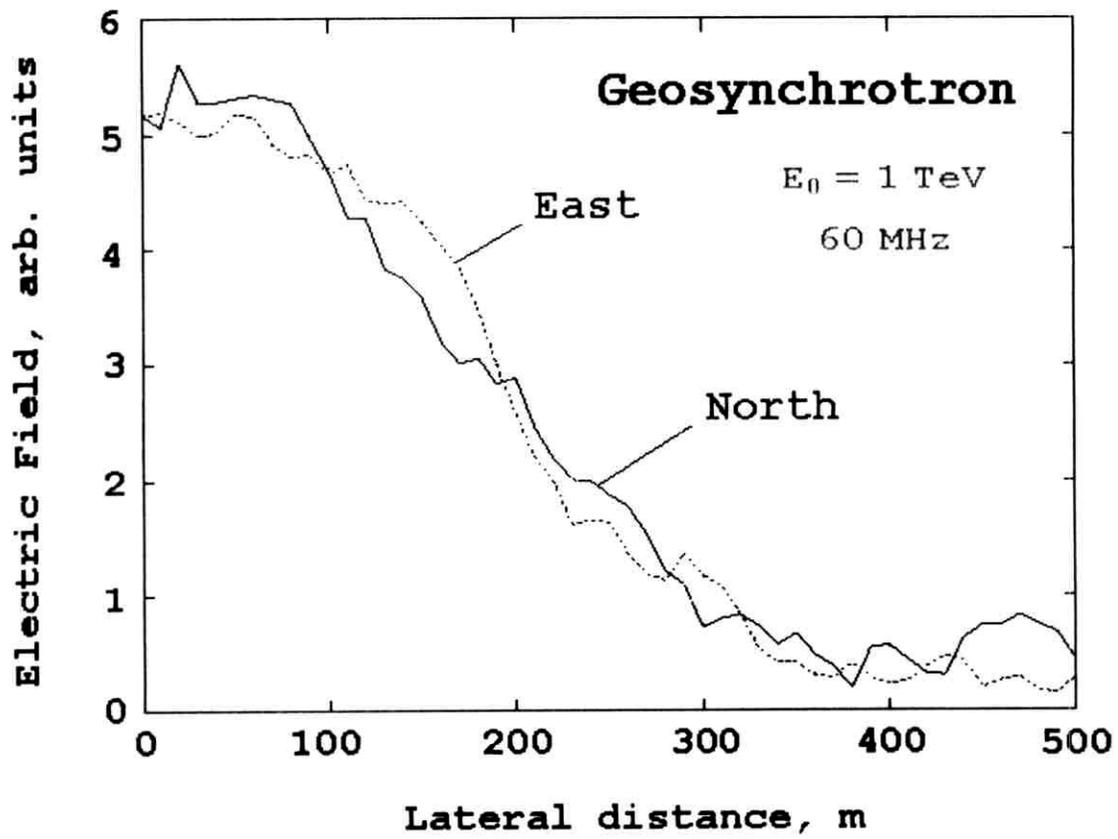
Azimuth dependence (1)

Conclusions & outlook

Cherenkov radiation demonstrates
diffraction pattern

Radiation is dominated by
geosynchrotron mechanism but

Some contribution from Cherenkov radiation,
especially when a shower axis is parallel to
the Earth's magnetic field

Realistic air shower and radio signal simulation

Calculation complementary to Huege & Falcke

More systematic investigations