rijksuniversiteit groningen / kvi - center for advanced radiation technology

LOFAR

Effects of atmospheric electric fields on radio emission from air showers

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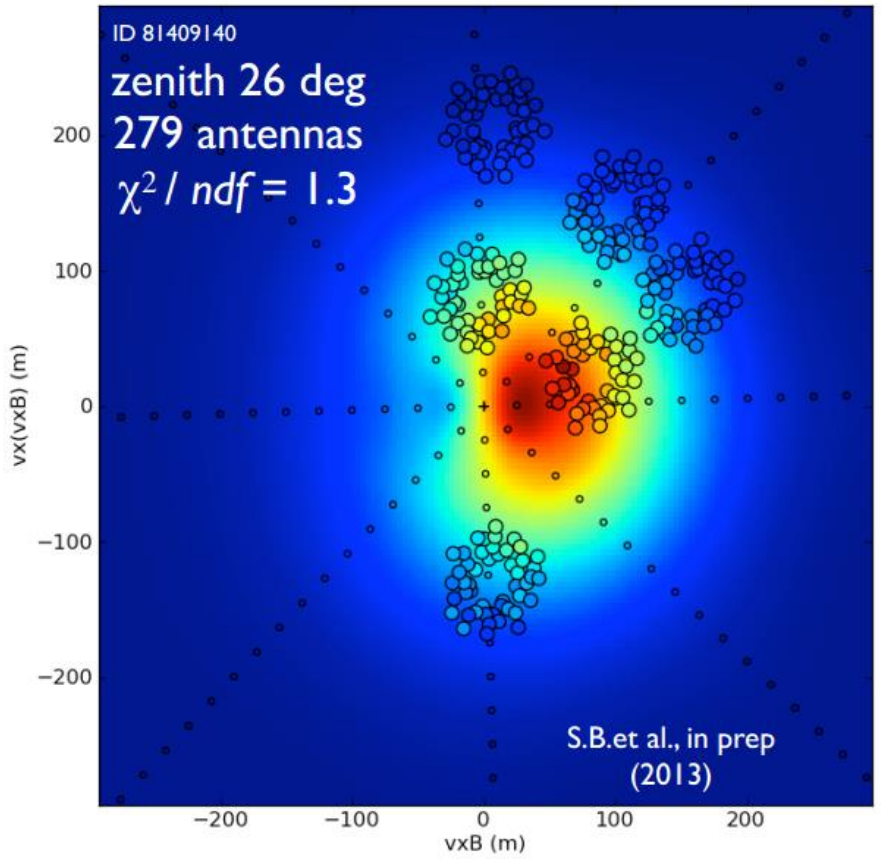
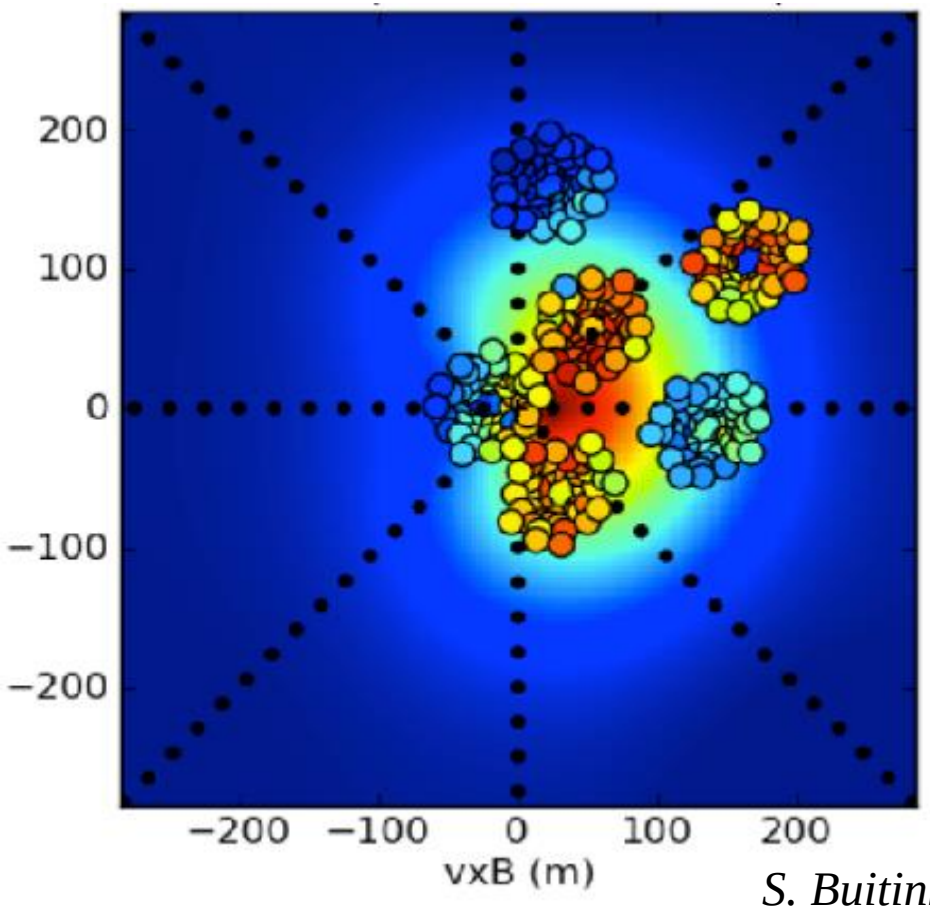
Cosmic Lightning Project & LOFAR Cosmic Ray KSP

CWI

FOM

Motivation





S. Buitink

Fair-weather condition

Thunderstorm condition

Study effects of atmospheric electric fields (E-fields) on radio emission by using CoREAS

Outline

- Radio emission mechanism
- Effects of E-fields on emission components
- Effects of E-fields on polarization and intensity footprints
- Summary and outlook

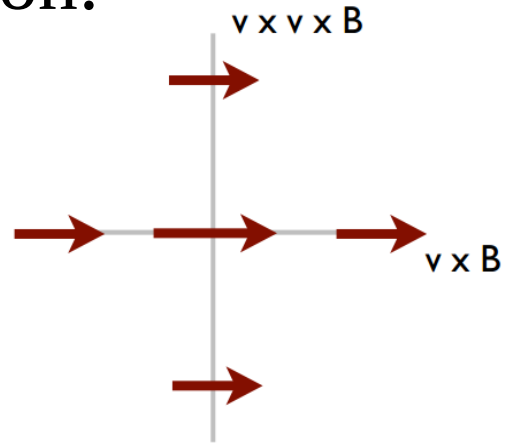
What causes radio emission?

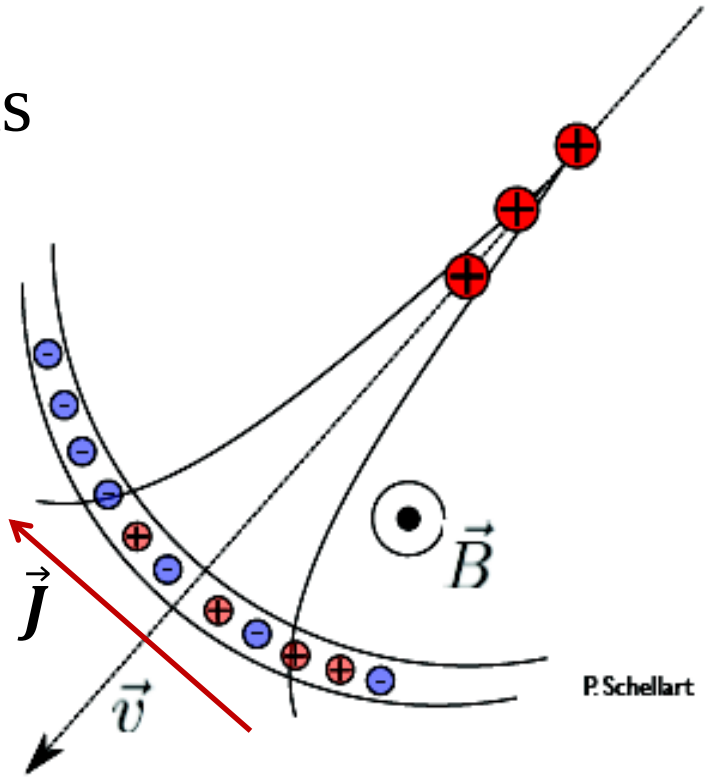
Geomagnetic field

+ Deflection of electrons and positrons

+ $E_{tc} \sim \frac{dJ}{dt} \sim v_d \frac{dN}{dt}$

+ Polarization:





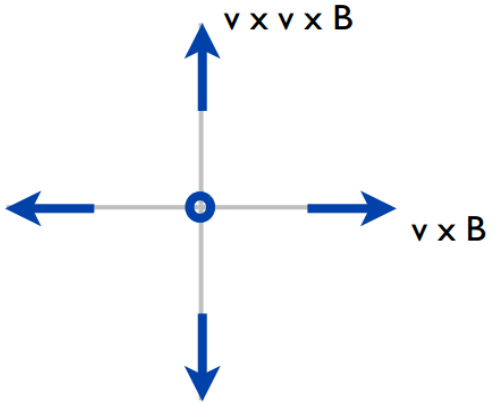
What causes radio emission?

Charge excess

+ Electrons are dominating

+ $E_{ce} \sim \frac{d(N_e - N_p)}{dt}$

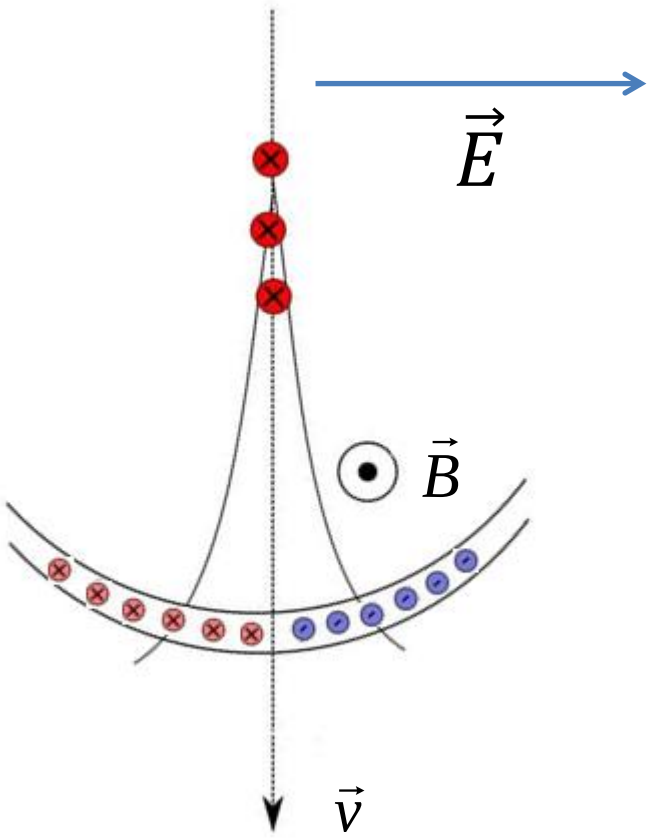
+ Polarization:

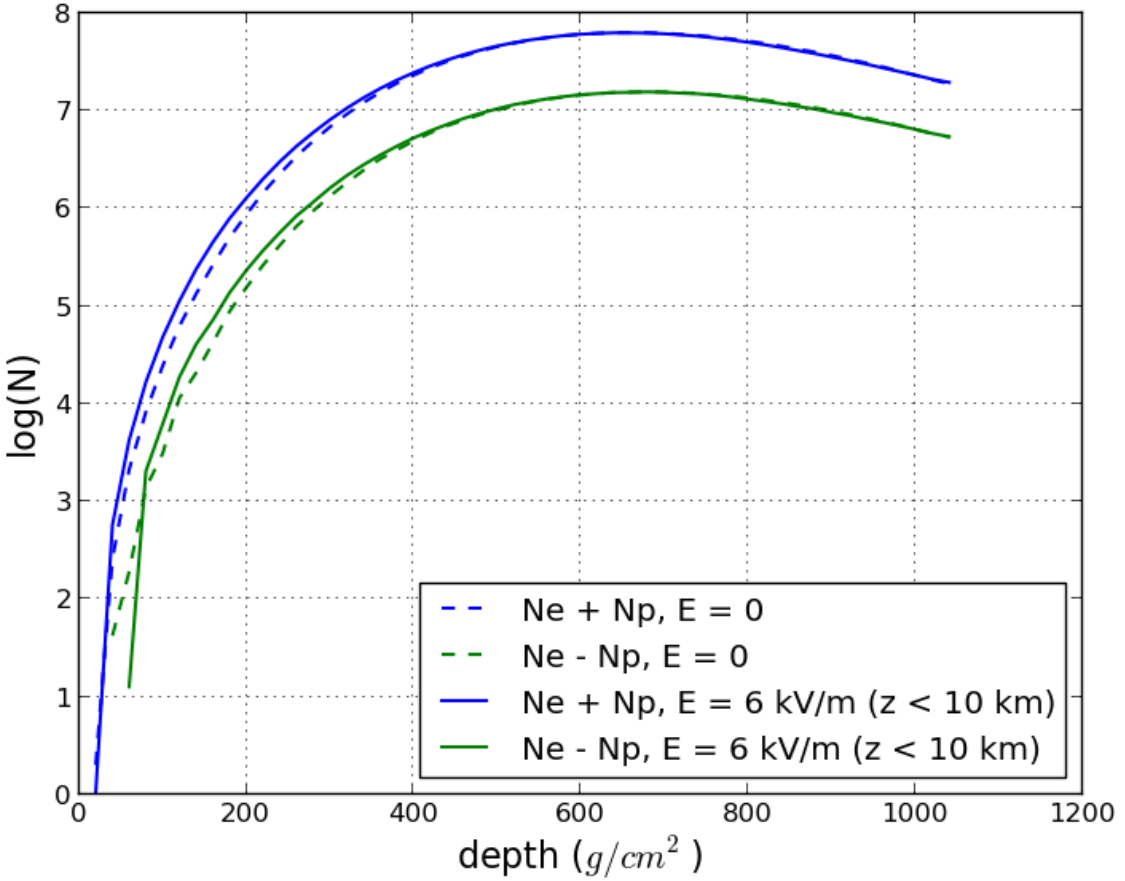


→ The full signal: $\vec{E} = \vec{E}_{tc} + \vec{E}_{ce}$ modified by the Cherenkov effect.

What are the effects of E-fields on radio emission?

A vertical shower in a horizontal E-field



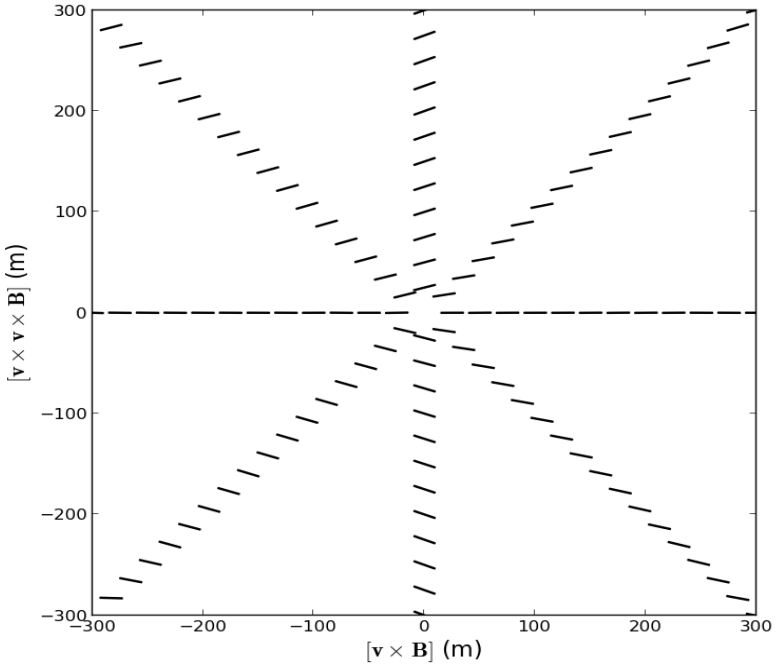


- Little effect on charge-excess component
- Strong effect on transverse-current component

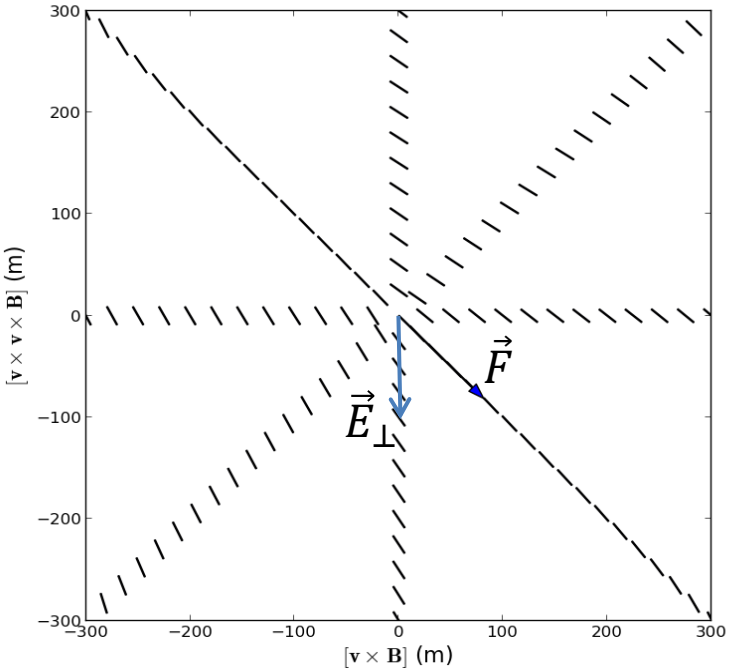
A vertical shower in a horizontal E-field

$\vec{E}_\perp$ changes the direction of the transverse-current to:

$$\vec{F} = q\vec{v} \times \vec{B} + q\vec{E}_\perp \, , \frac{F_C}{F_L} \approx 1$$



$E = 0$



$E_{//} = 0, E_\perp = 6$ kV/m

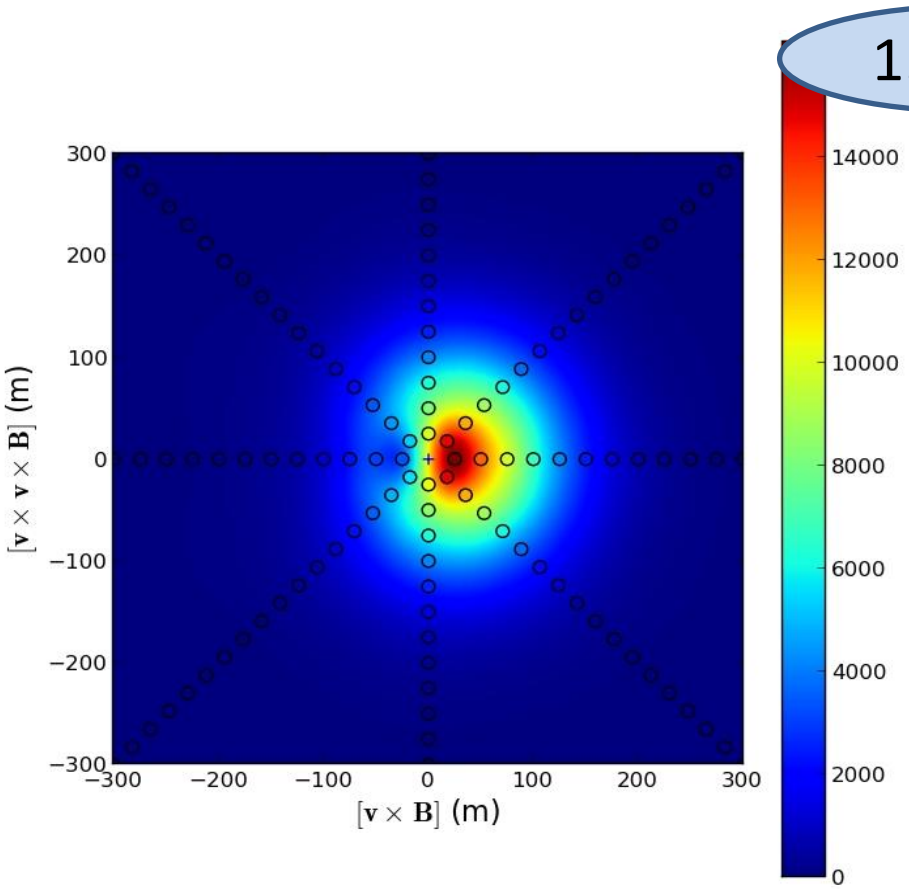
($\perp$ to shower)

+ Polarization: change direction to $\vec{F}$

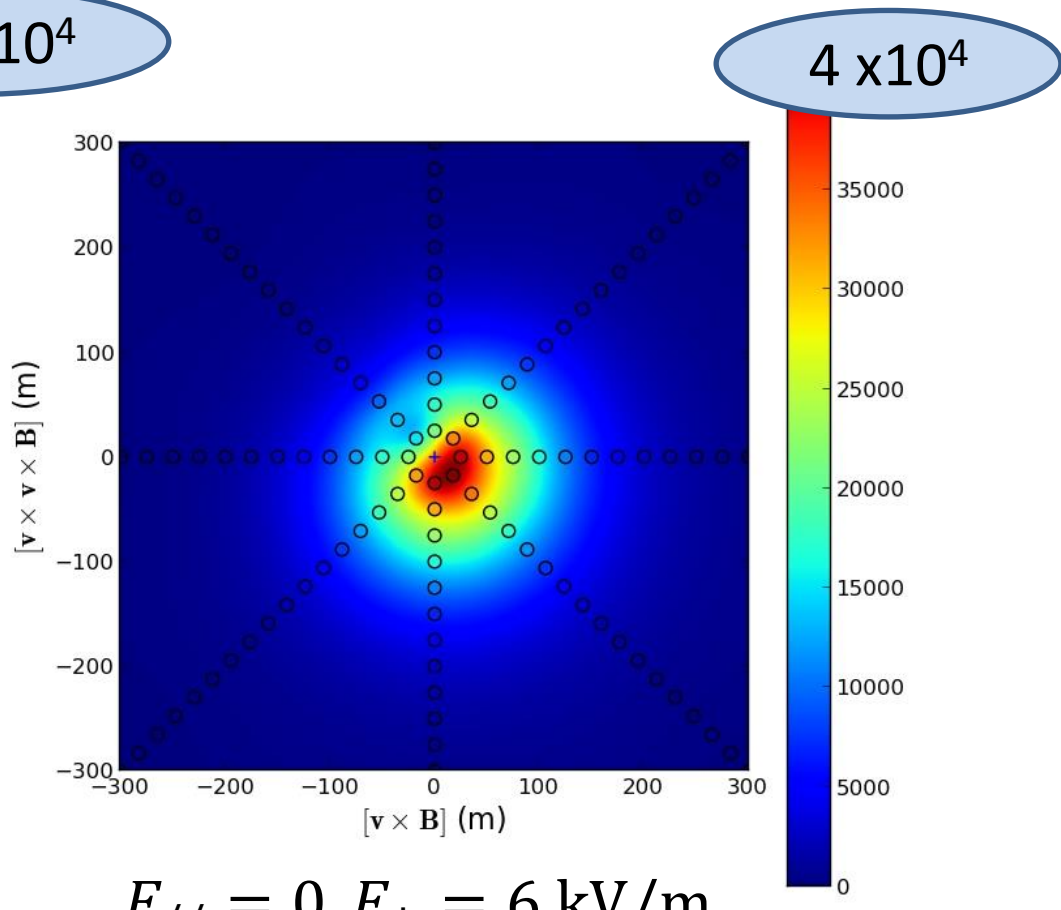
A vertical shower in a horizontal E-field

+ Amplitude: change due to the increasing transverse current

$$I \sim E^2 \sim (v_d)^2$$



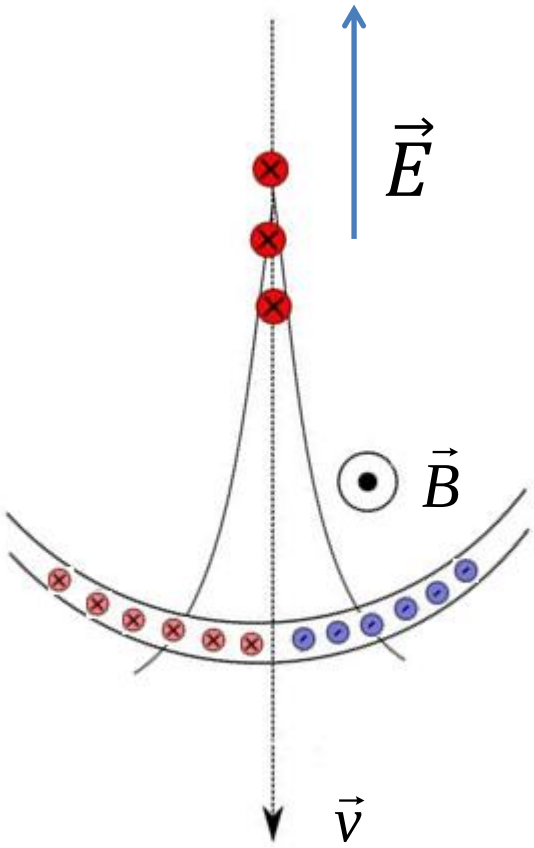
$E = 0$

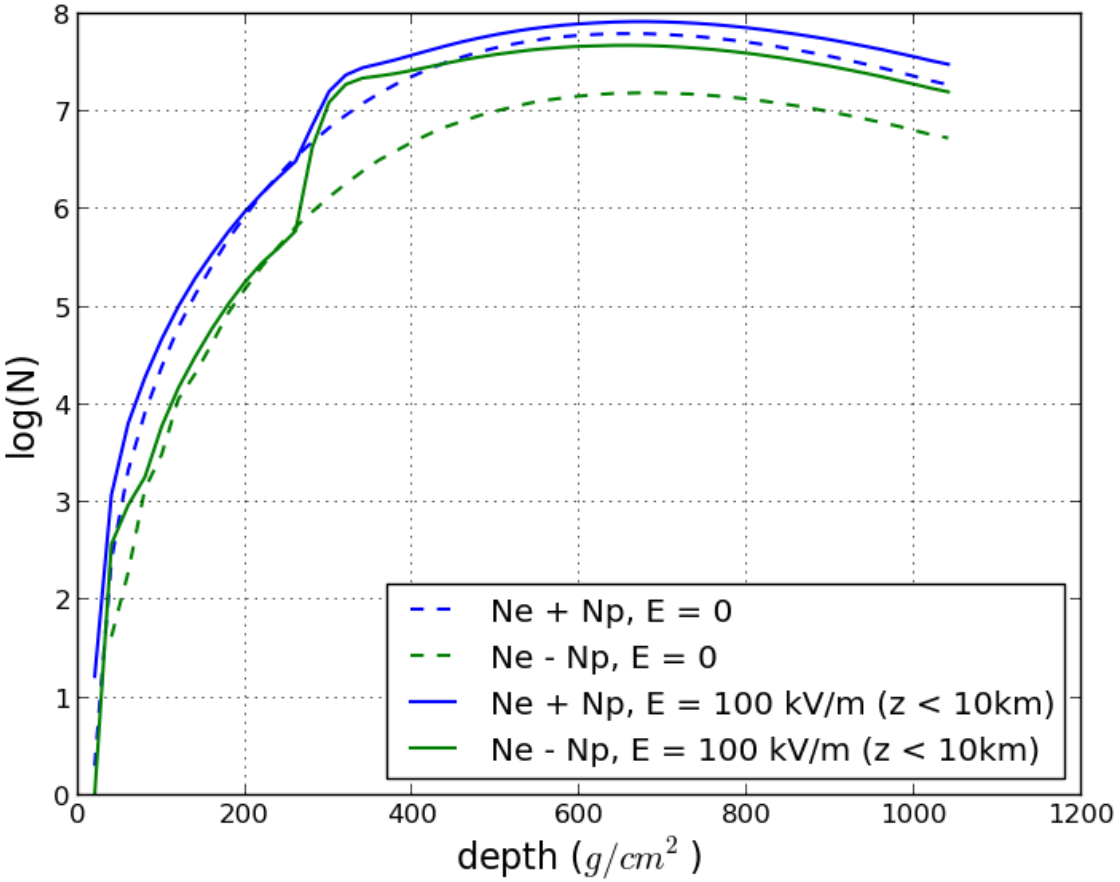


$E_{//} = 0, E_{\perp} = 6$ kV/m

($\perp$ to shower)

A vertical shower in a vertical E-field

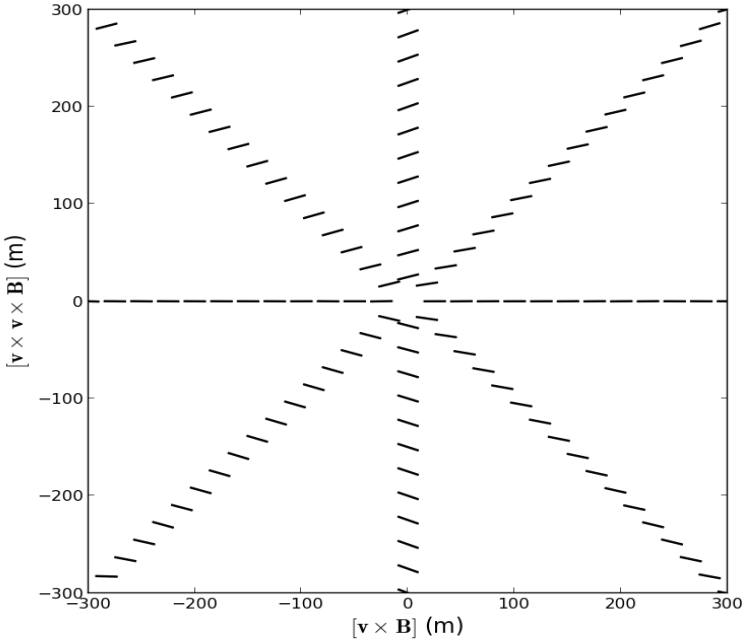




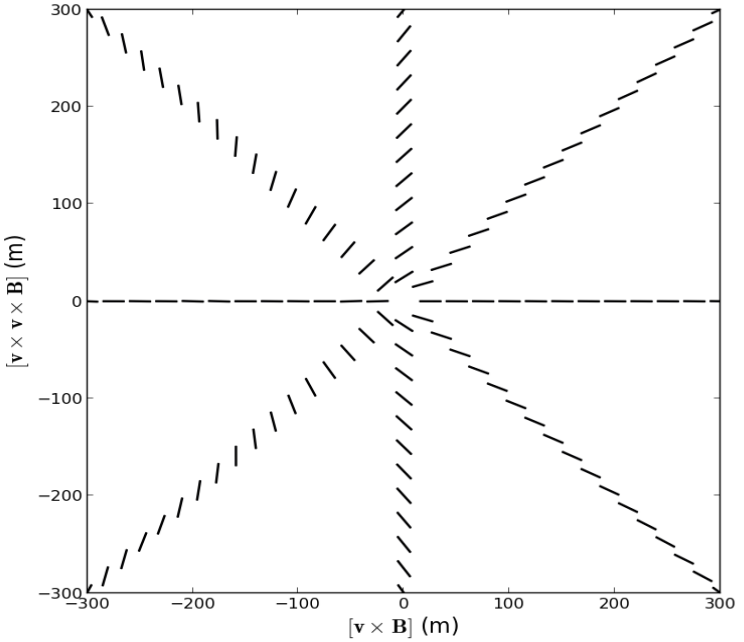
- Small effect on transverse-current component
- Charge-excess component enhanced

A vertical shower in a vertical E-field

$\vec{E}_{//}$ changes the amount of charge-excess.



$E = 0$



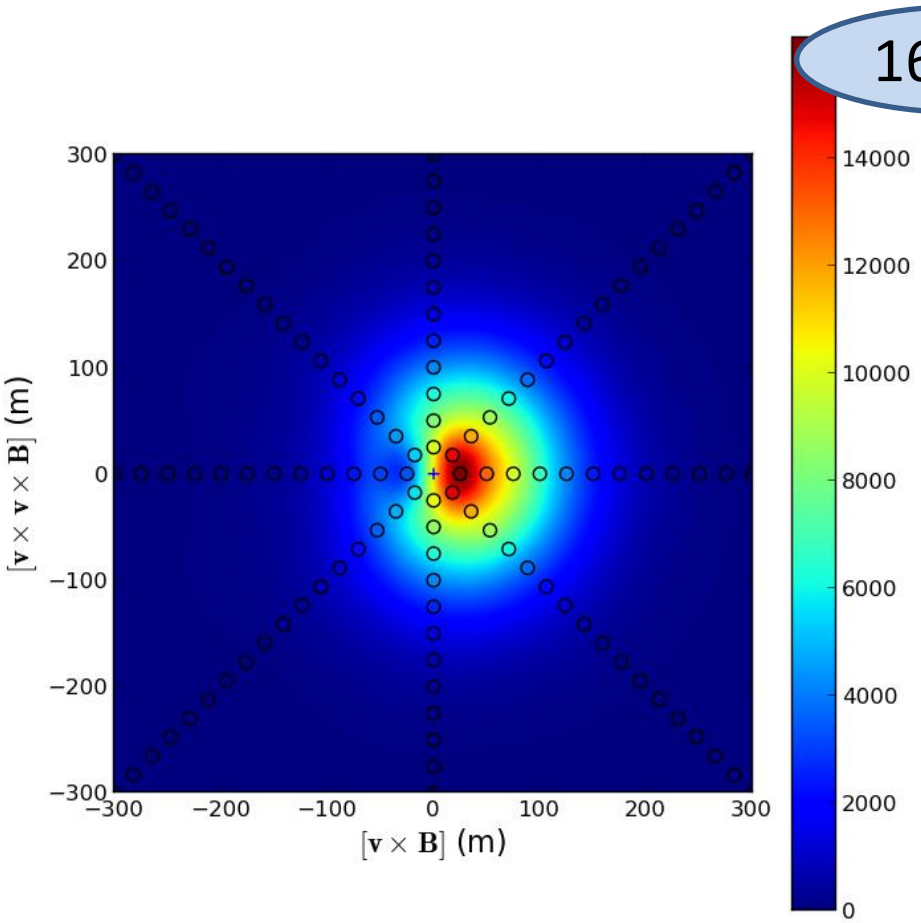
$E_{//} = 100\ \mathrm{kV/m}, E_{\perp} = 0$

(// to shower)

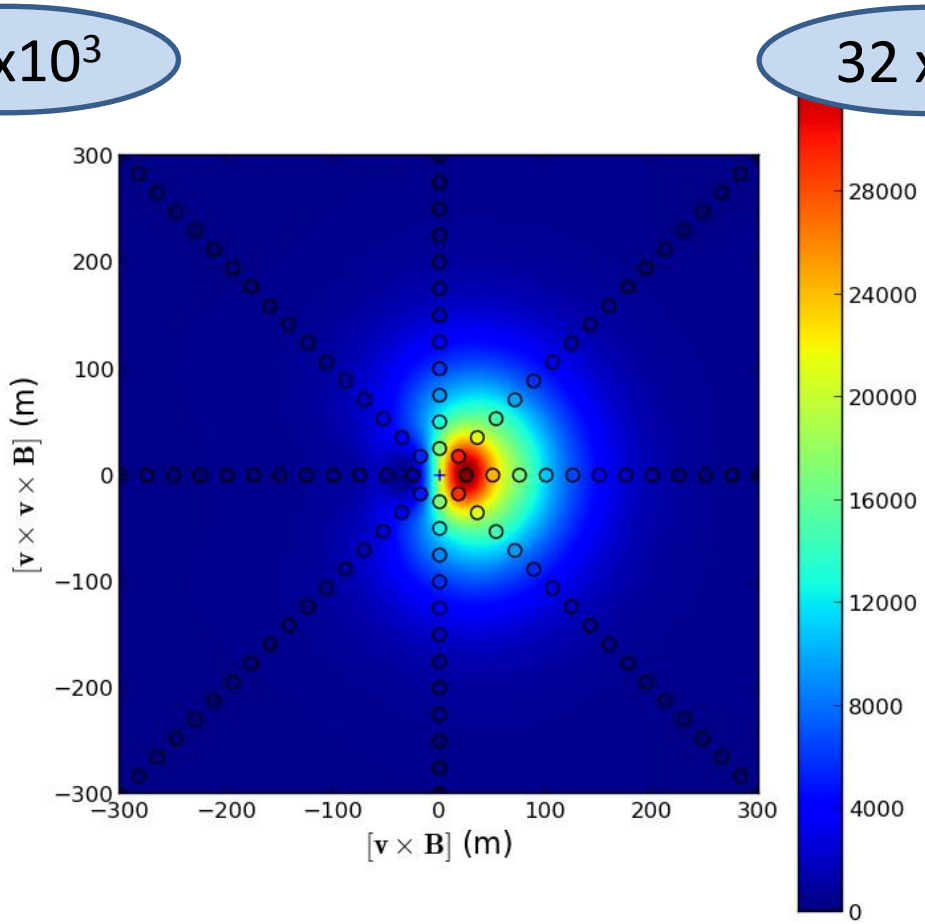
+ Polarization: more radial

A vertical shower in a vertical E-field

+ Amplitude: increase by factor two



$E = 0$



$E_{//} = 100\ \mathrm{kV/m}, E_{\perp} = 0$

(// to shower)

Effects of E-fields on radio emission

$$\vec{E} = \vec{E}_{//} + \vec{E}_{\perp}$$

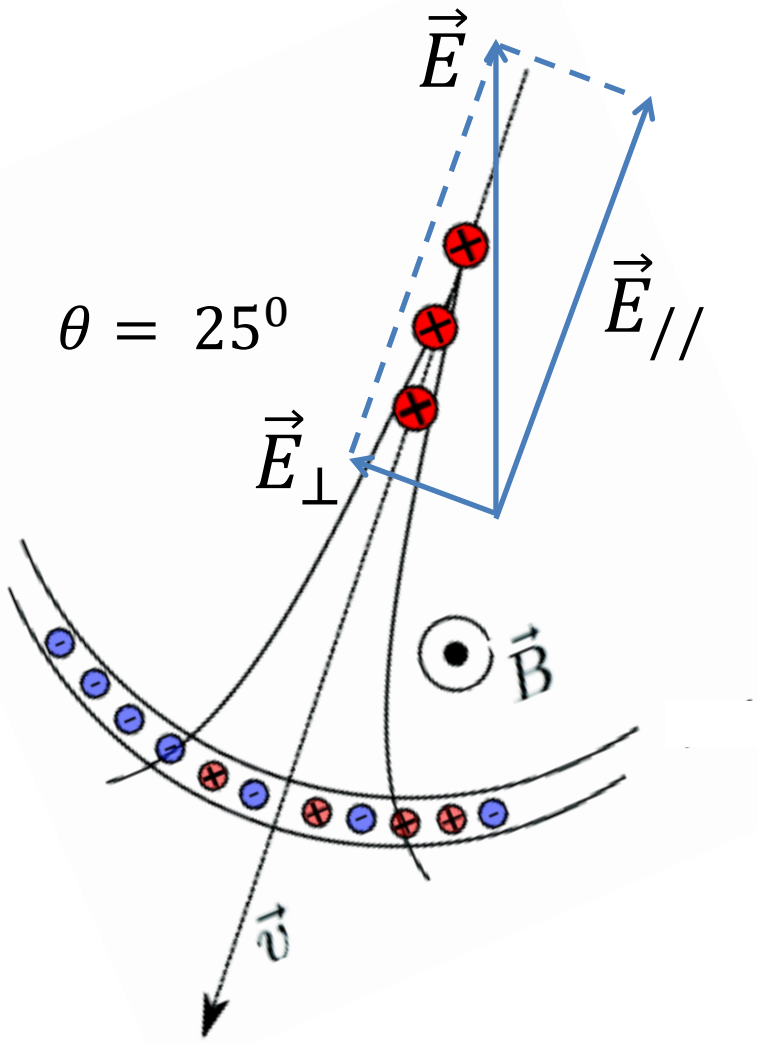
Charge-excess component

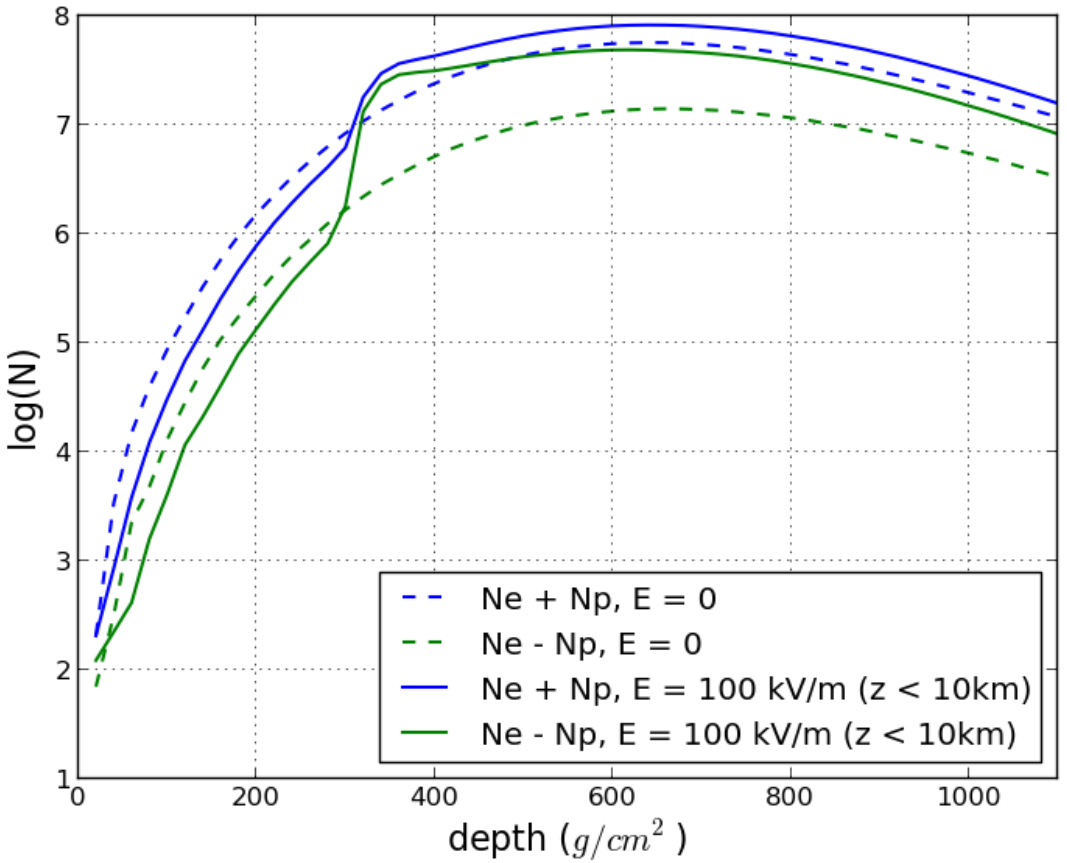
- Amplitude: 0/+
- Polarization: more radial

Transverse-current component

- Amplitude: ++
- Polarization: direction changes

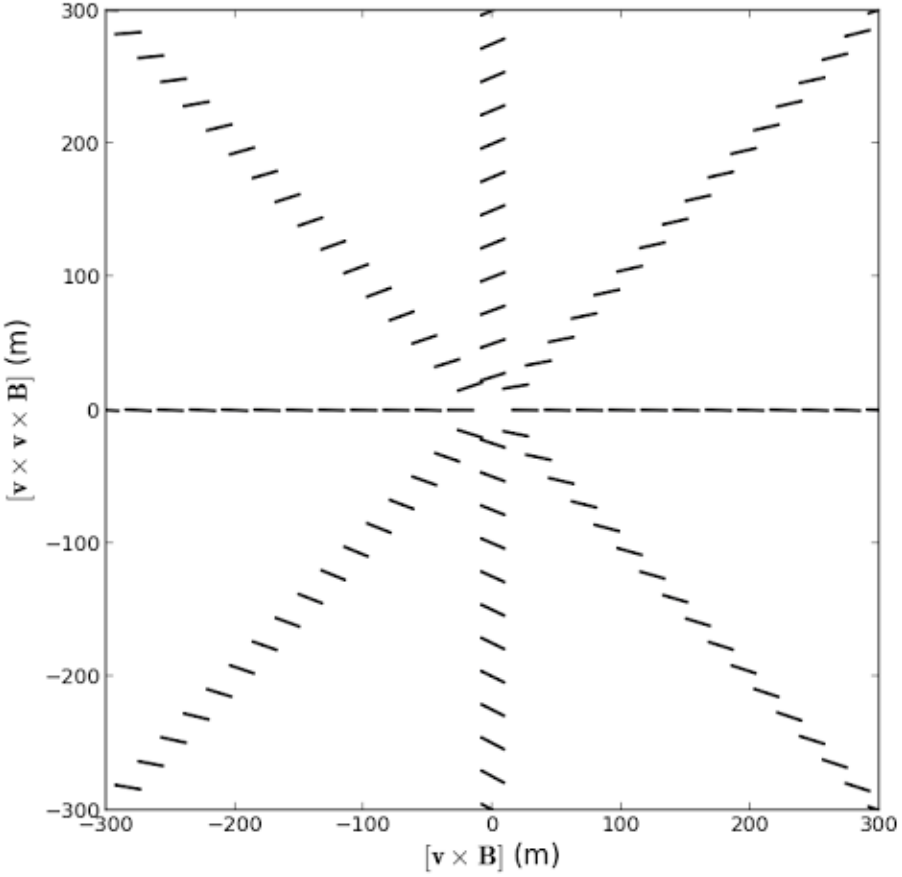
An inclined shower in a vertical E-field



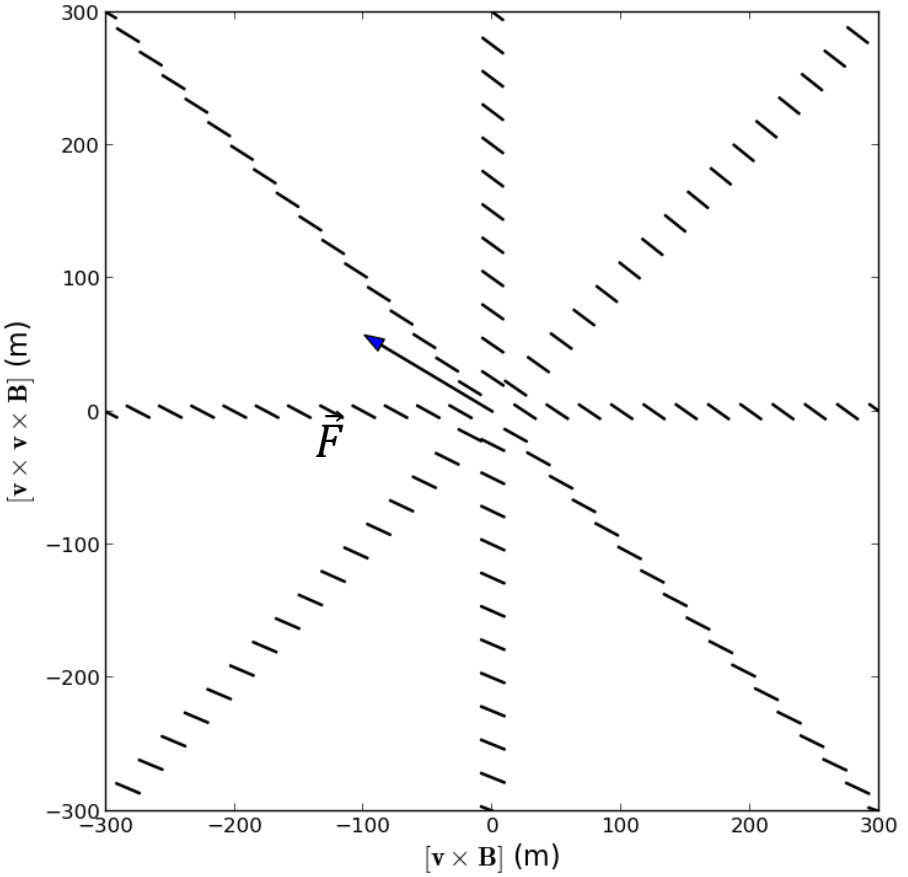


Both transverse-current and charge-excess components change

An inclined shower in a vertical E-field



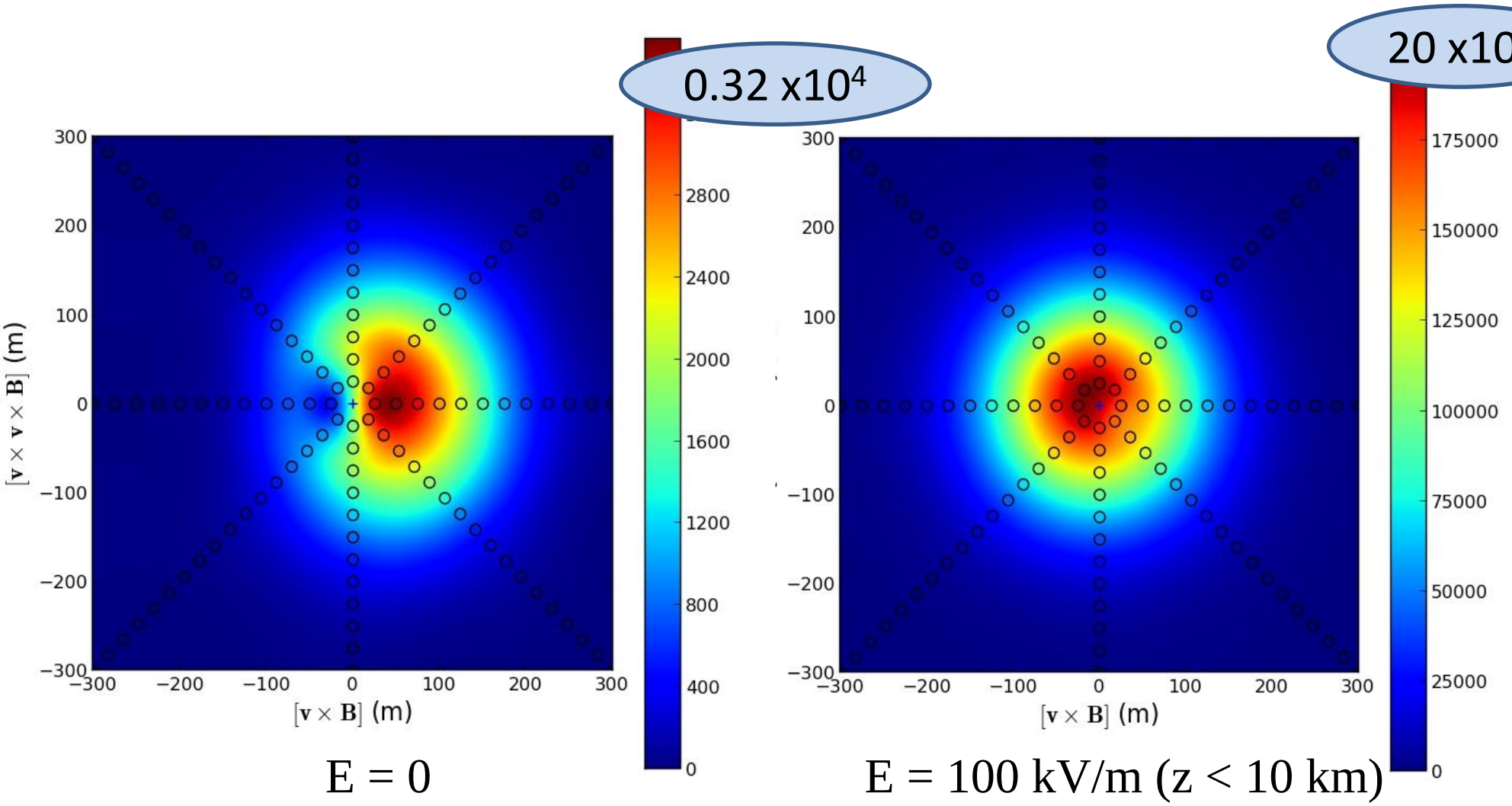
E = 0



E = 100 kV/m (z < 10 km)

+ Polarization: change direction to $\vec{F} = q\vec{v} \times \vec{B} + q\vec{E}_{\perp}$

An inclined shower in a vertical E-field



E = 0

E = 100 kV/m (z < 10 km)

+ The maximum value: change to another position.

+ Amplitude: strongly enhanced

Summary and outlook

- Summary:

+ The effects of homogeneous E-fields on the transverse current and charge excess are understood.

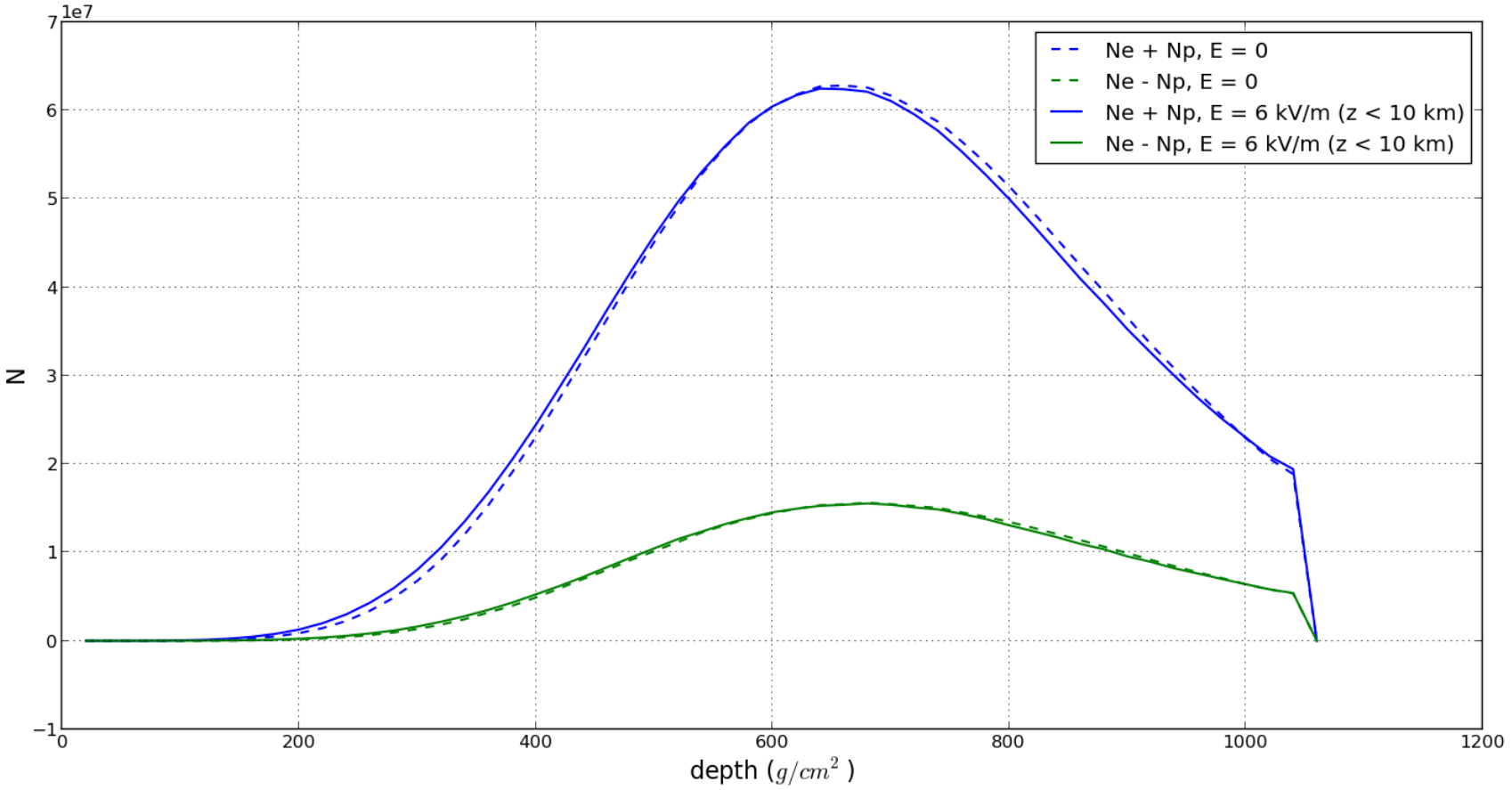
- Outlook:

+ Find the quantitative relation between E-fields and the charge excess

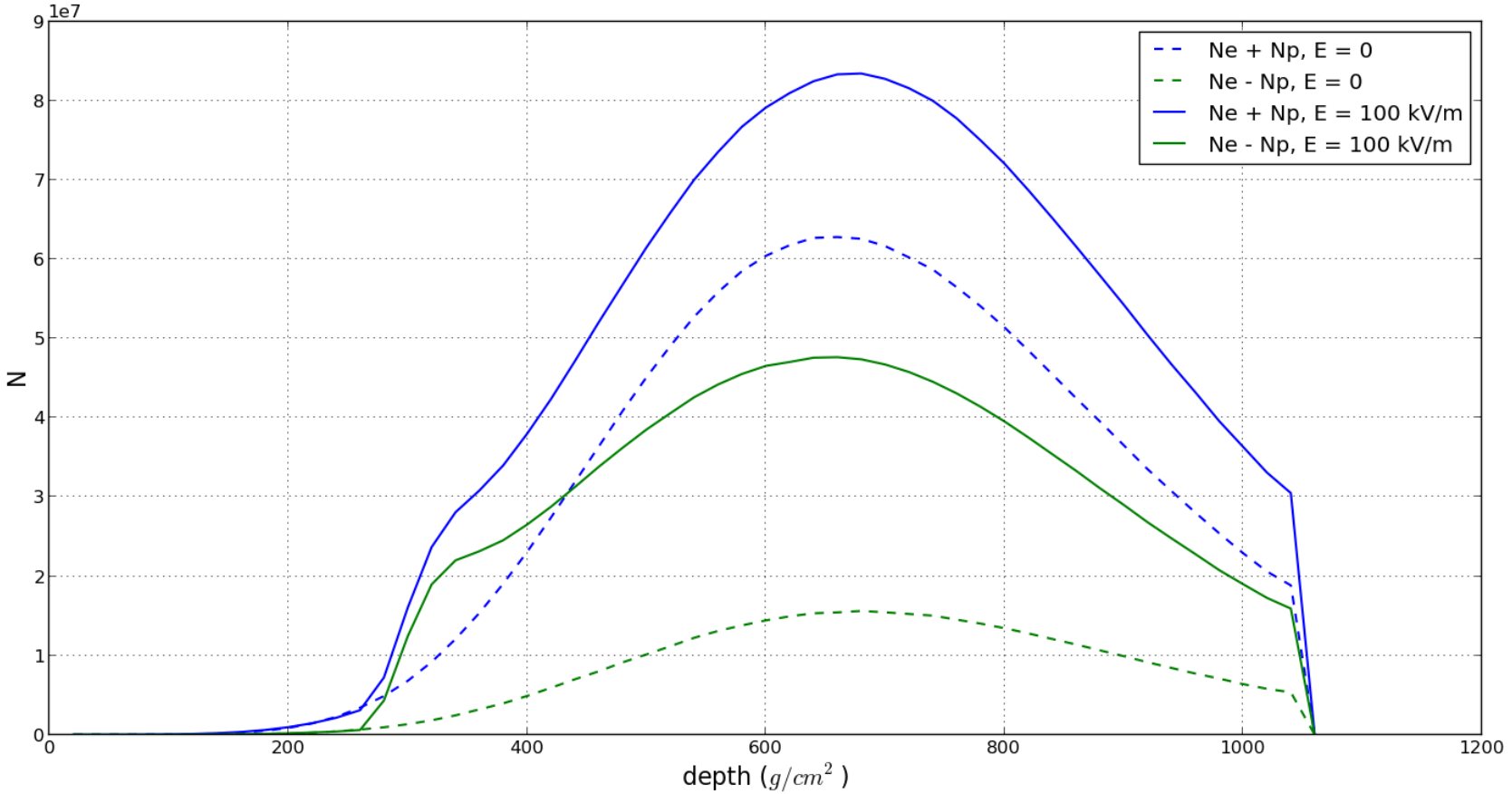
+ Treat a more realistic electric field that varies with the altitude within and around thunderclouds

+ Use the results to study about the properties of atmospheric electric fields

A vertical shower in a horizontal E-field



A vertical shower in a vertical E-field



An inclined shower in a vertical E-field