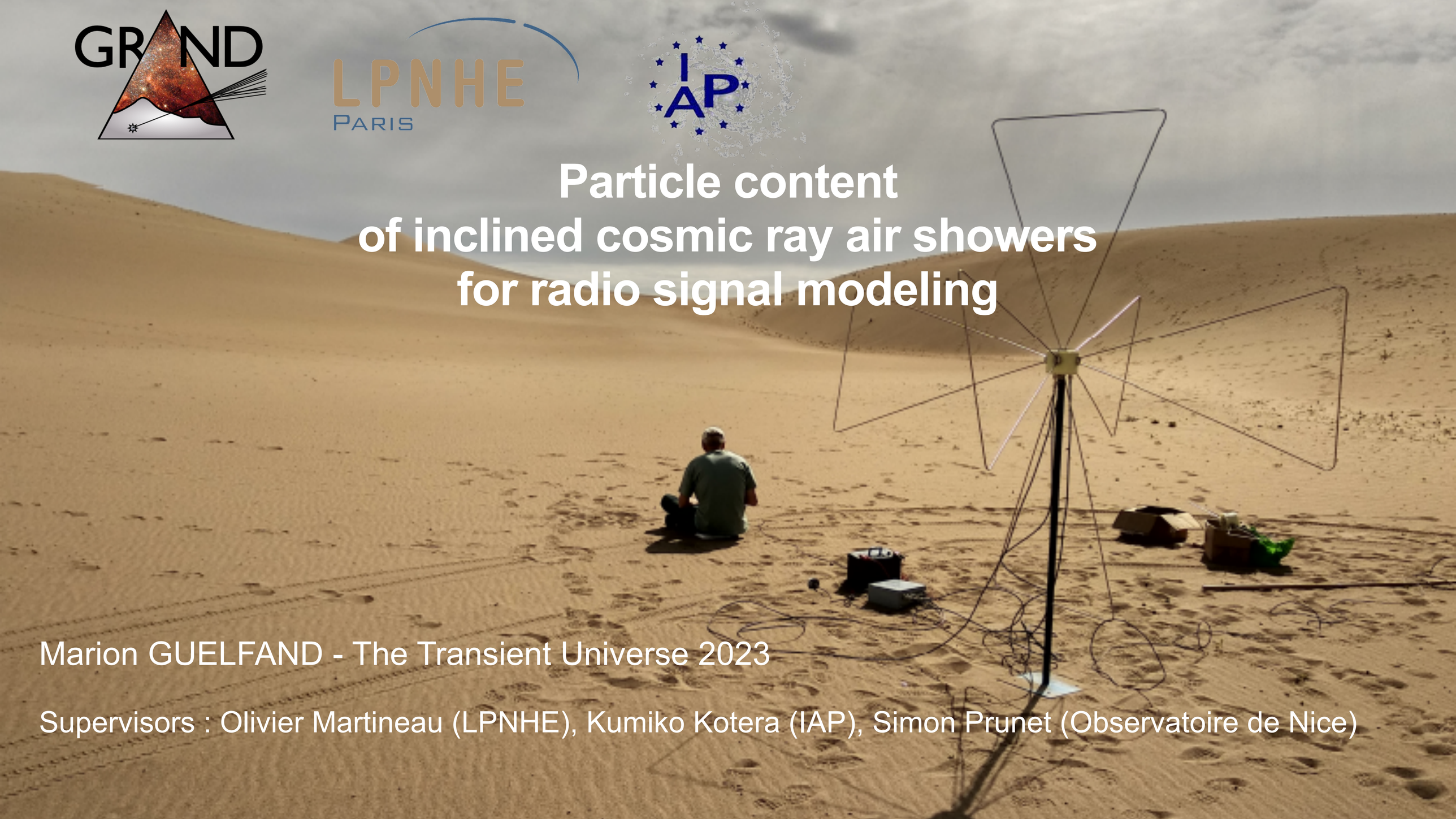


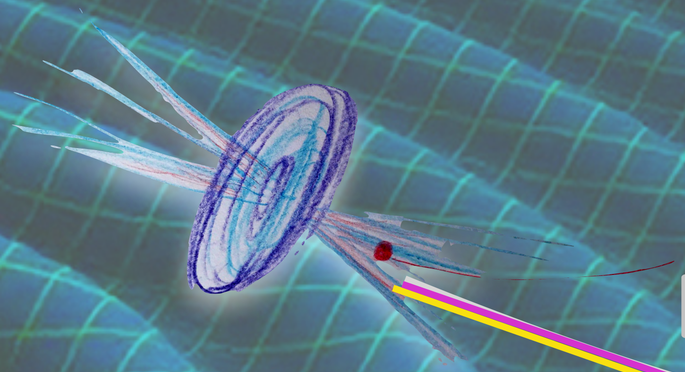
Particle content of inclined cosmic ray air showers for radio signal modeling

Marion GUELFAND - The Transient Universe 2023

Supervisors : Olivier Martineau (LPNHE), Kumiko Kotera (IAP), Simon Prunet (Observatoire de Nice)

Exploring the high-energy Universe with multi-messengers

A lot of unknown in the ultra high energy (UHE) range:
- Ultra high energy gamma rays and neutrinos not detected yet
- Cosmic rays sources not discovered



Gravitational waves

Cosmic rays

p Fe

Gamma rays

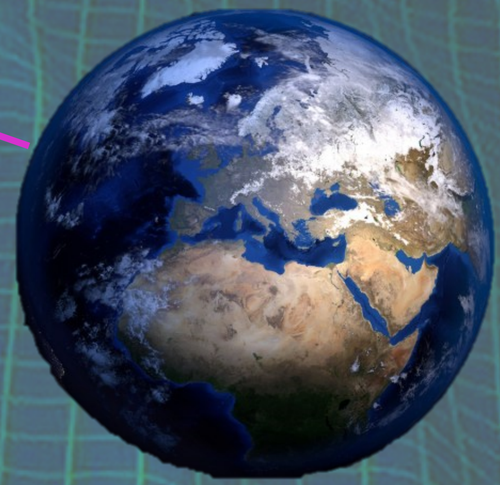
γ

γ

ν

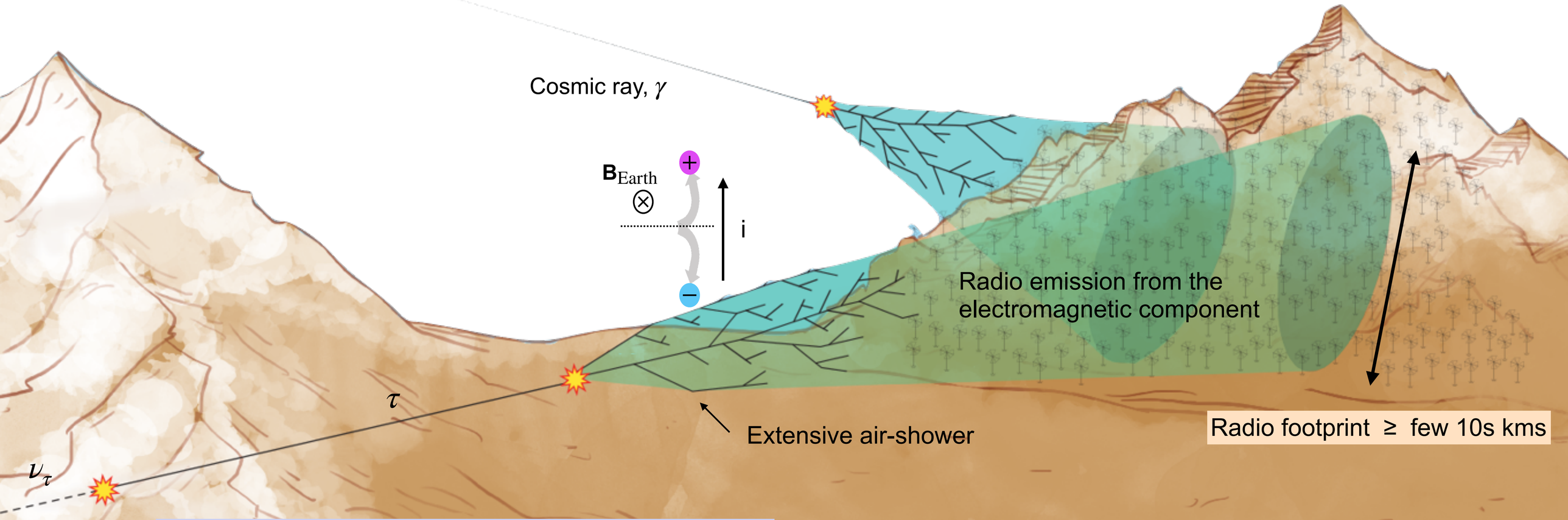
ν

Neutrinos



Very low fluxes of UHE particles:
- **Large observatories** needed to collect the various messengers

Radio-detection of air-showers



Giant Radio Array for Neutrino Detection (GRAND): multi-messenger observatory of 200 000 radio antennas deployed over 200 000 km²

Radio antennas: cheap, robust, scalable
Can be deployed over large areas

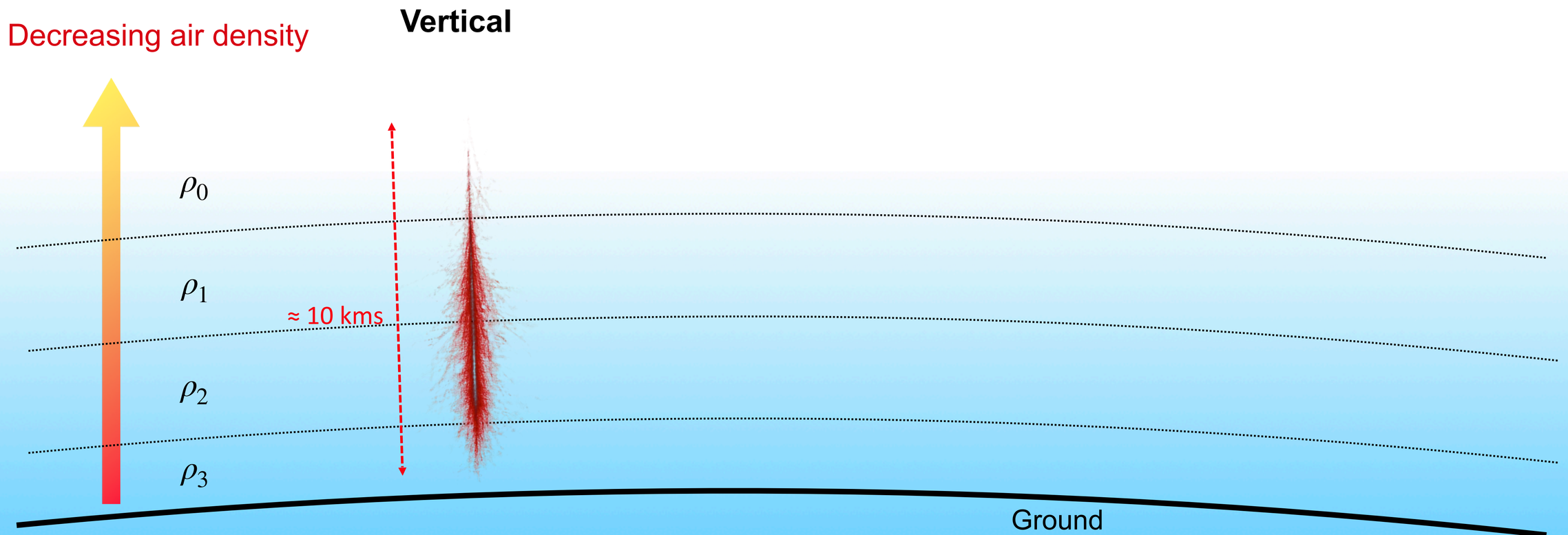
Very inclined air-showers → large footprints → sparse antenna array → large observatories

Specific signatures for very inclined air-showers

Vertical air-showers well understood. New challenges with inclined air-showers:

- Lower atmospheric density
- Different geometries
- Reflection from ground

Radio signal strongly affected



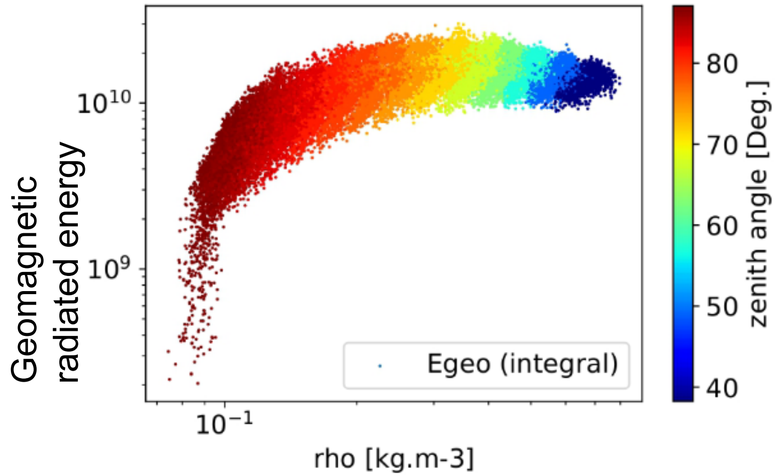
Specific signatures for very inclined air-showers

Vertical air-showers well understood. New challenges with inclined air-showers:
- Lower atmospheric density
- Different geometries
- Reflection from ground

Radio signal strongly affected → coherence loss

- **Particle content and distribution**
- **Lateral extension of very inclined air-showers ?**

Chiche, Zhang, Kotera, Huege, de Vries, Schlüter, Tueros, in prep



Decreasing air density

Vertical

Lateral extent

Inclined

Drift due to geomagnetic field B_{Earth}

ρ_0

ρ_1

ρ_2

ρ_3

≈ 10 kms

≈ 100 kms

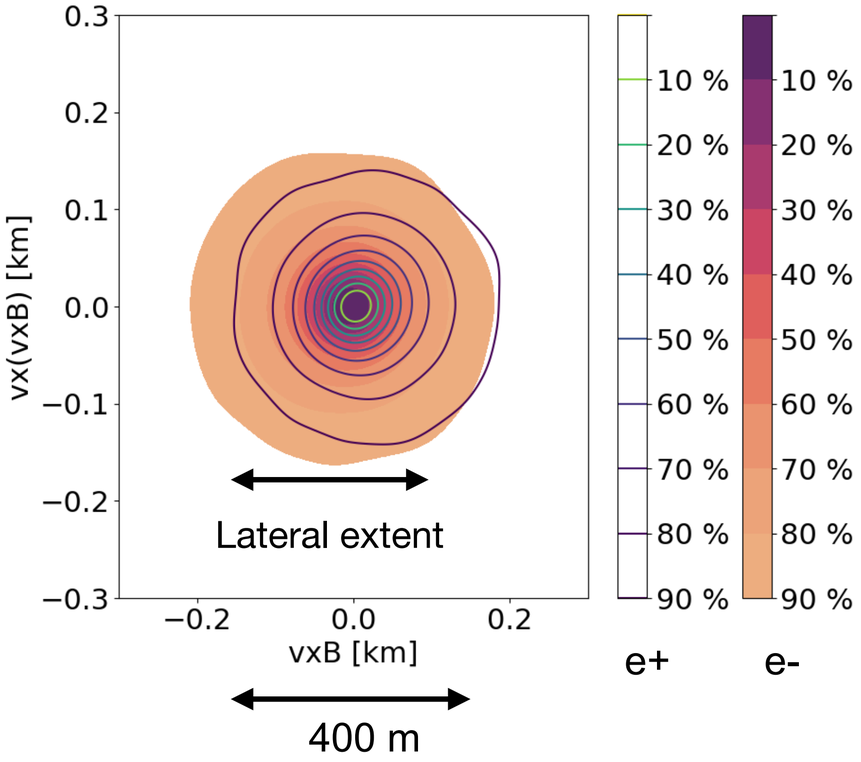
Particles in the shower

Ground

Distributions of particles in the shower plane

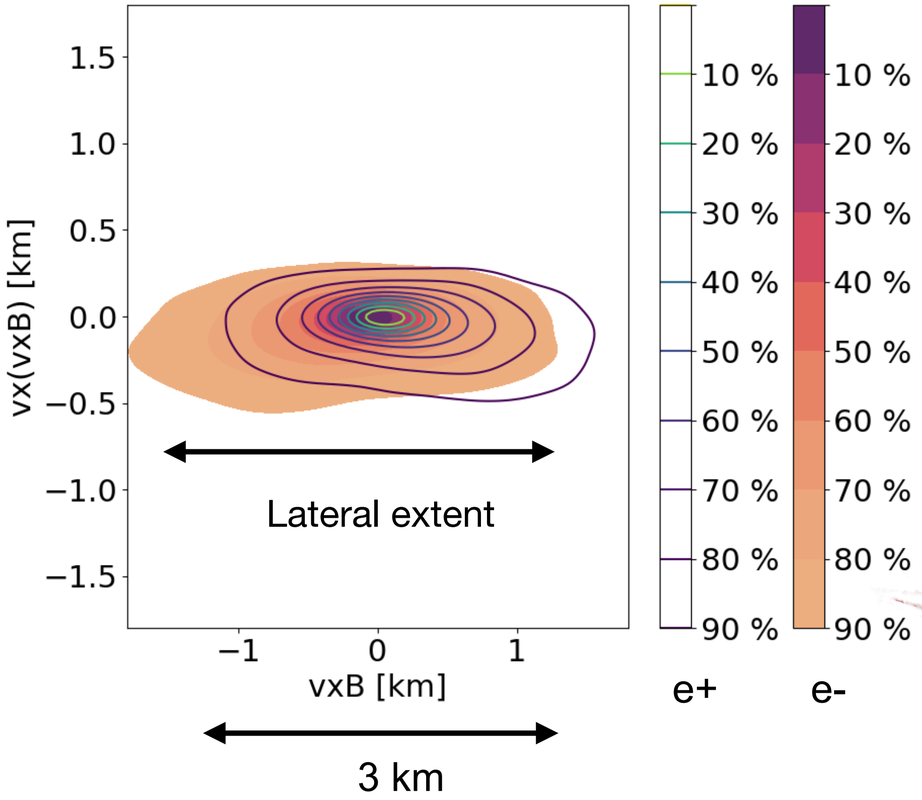
Monte Carlo simulations with CORSIKA and CoREAS

θ = 65° « vertical »



High ρ_{air} and strong B_{Earth}

θ = 86° very inclined

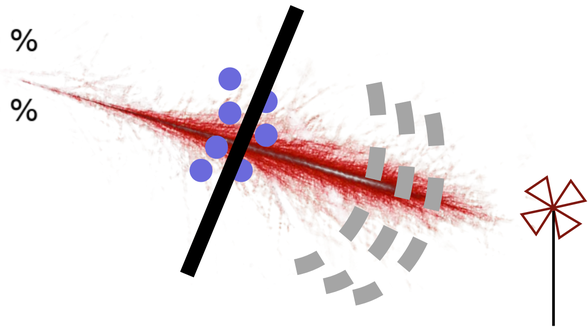


Low ρ_{air} and strong B_{Earth}

Lorentz force:

$F_{Lorentz} = qv \times B_{Earth}$

Shower plane

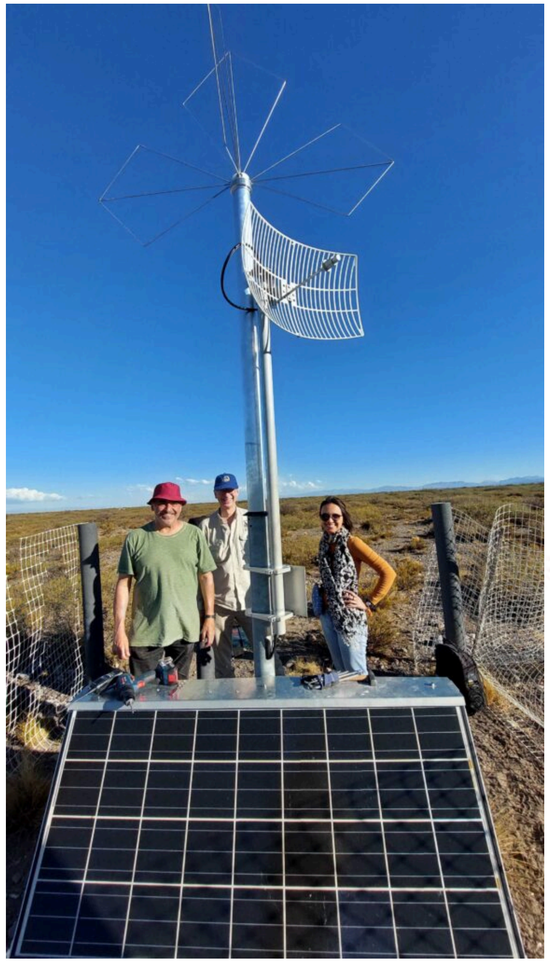


Drift and charge separation due to B_{Earth}

Charge separation and **drastic lateral extent increase**

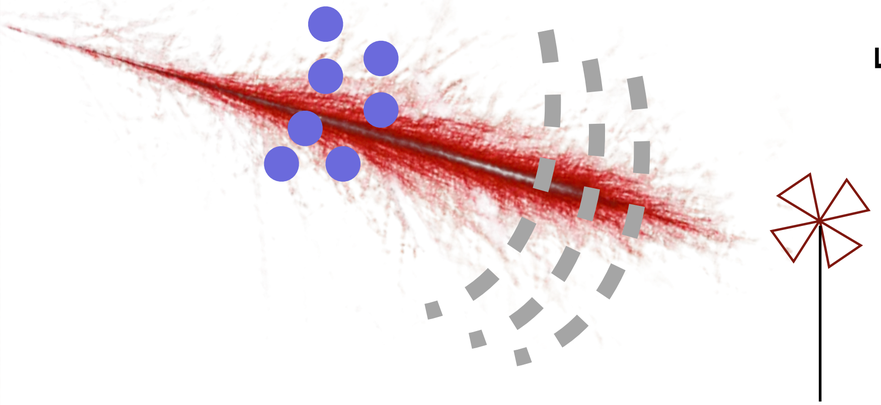
- Particle content which emits in radio?

Contribution of particle energies to radio emission

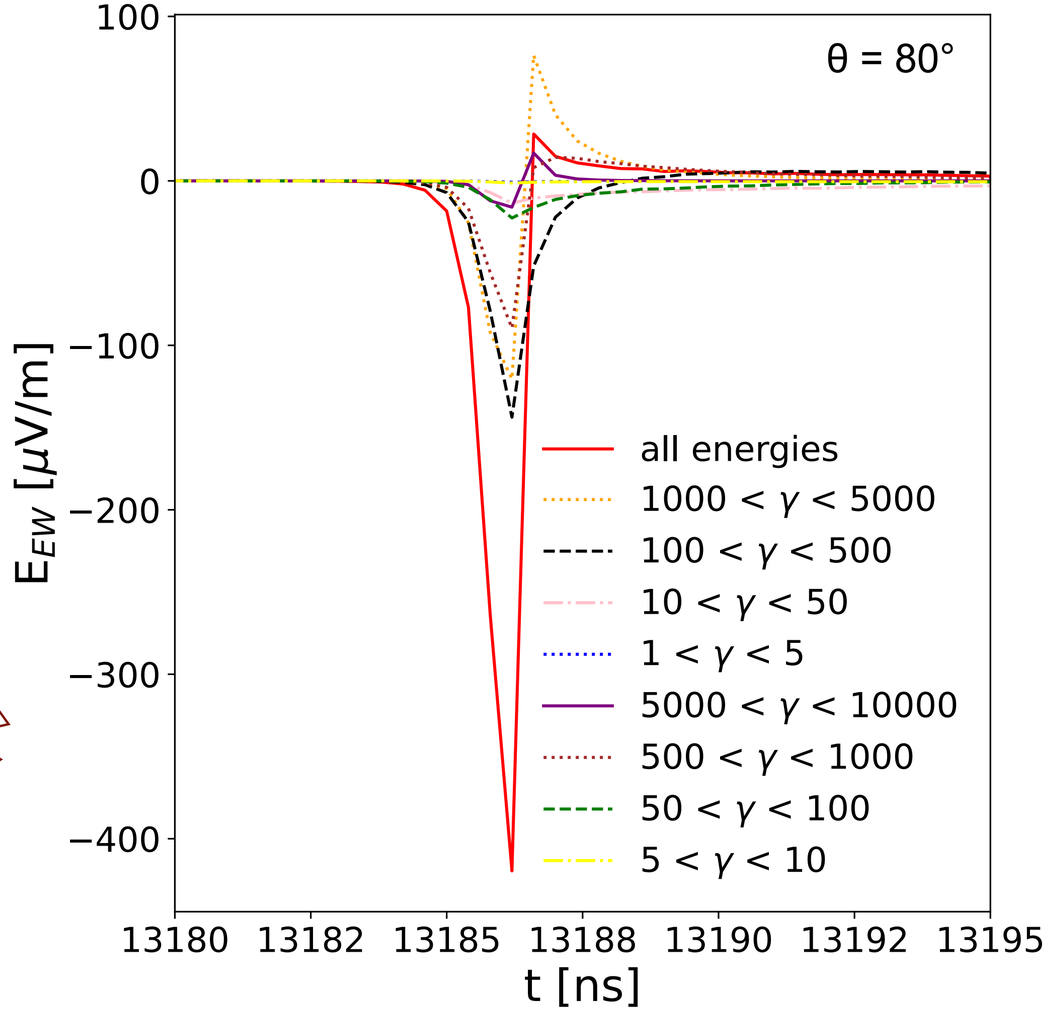


$$E = \gamma m_e c^2$$

With γ = Lorentz factor
and $m_e = 0.511$ MeV

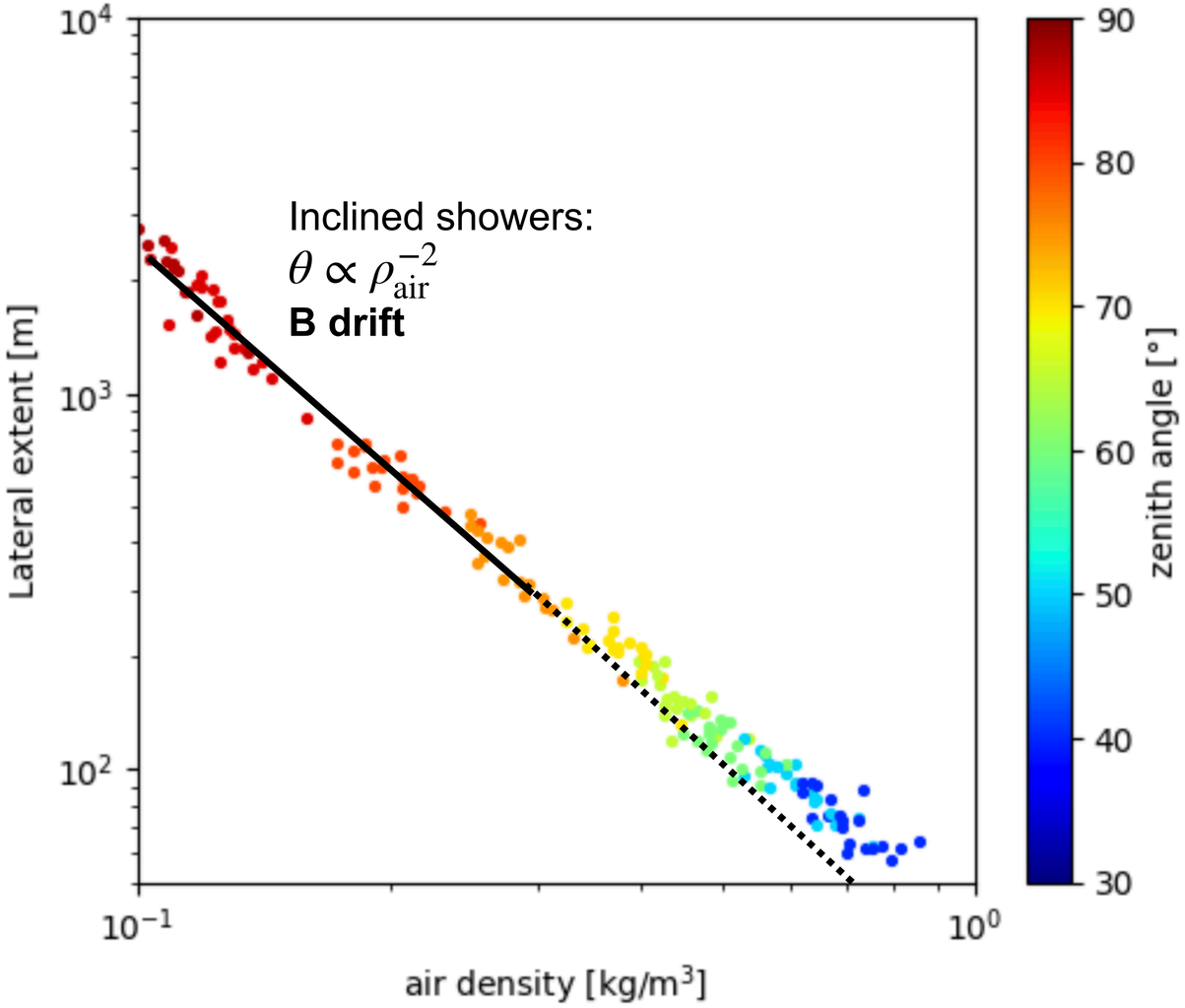


Contribution of different particle energy regimes to the radio pulses



- Contribution in the range 50-2500 MeV
- Quantify the lateral extent of these particle energy regimes responsible for the radio signal

Particle content & distribution for inclined air-showers



Simulations

Estimation of the lateral extent:
Radius containing 90% of the particles
in the energy range 50 - 2500 MeV

Scholten et al, 2007

Analytical

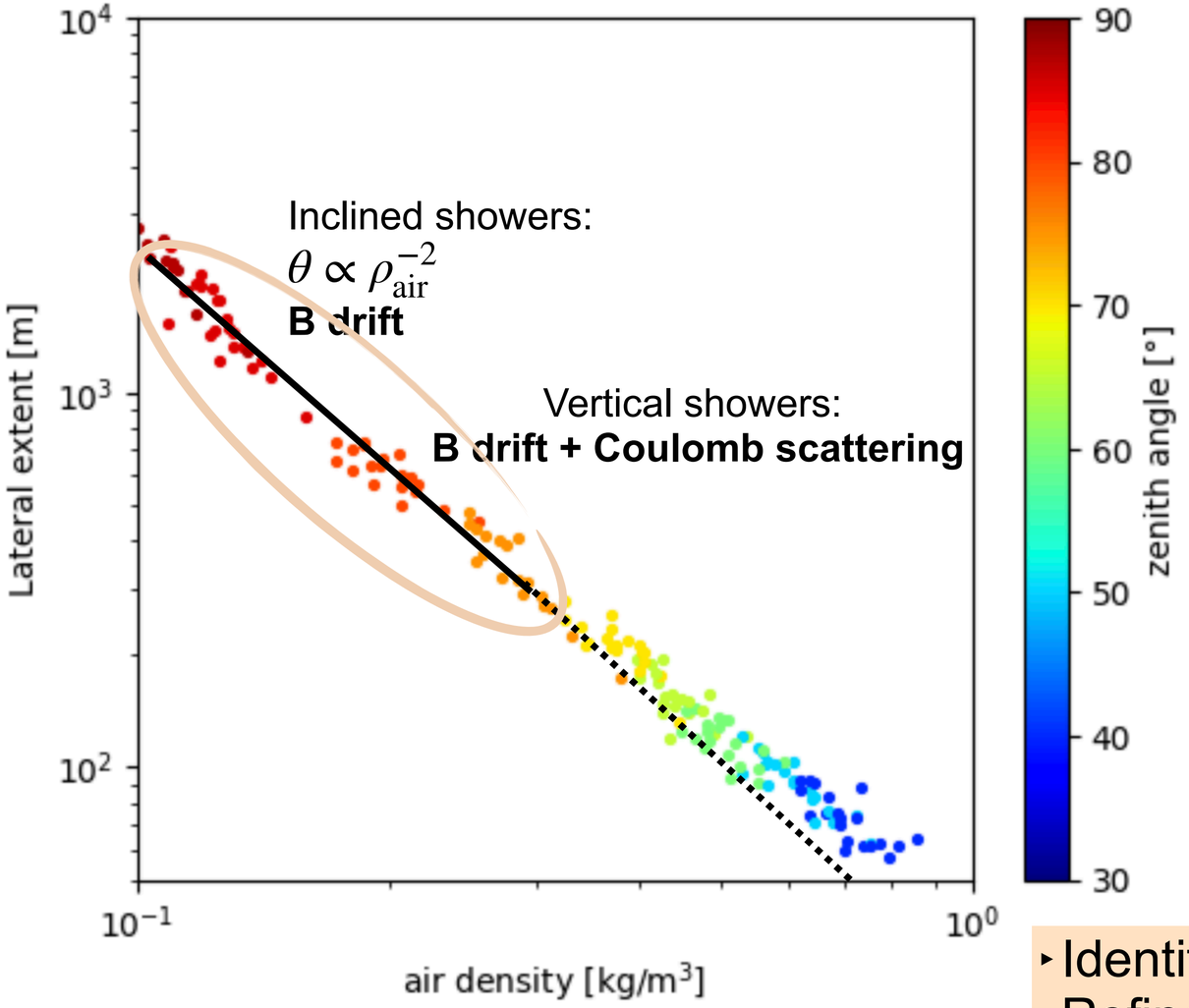
Calculation of L_{lat} from drift (effect of B_{Earth}):

$$L_{\mathrm{drift}} = 2x_{\mathrm{transverse}}(t = \tau)$$

Particle transverse velocity: $v_{\mathrm{transverse}}(t) = \frac{\tau c^3 e B_{\mathrm{Earth}}}{\mathscr{E}(t)}(1 - e^{-t/\tau})$

Particle transverse position: $x_{\mathrm{transverse}}(t) = \frac{\tau^2 c^3 e B_{\mathrm{Earth}}}{\mathscr{E}_0}(e^{t/\tau} - 1 - \frac{t}{\tau})$

Particle content & distribution for inclined air-showers



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- Identification of new physical regimes for inclined air-showers
- Refine analytical model for lateral extent for all inclination regimes