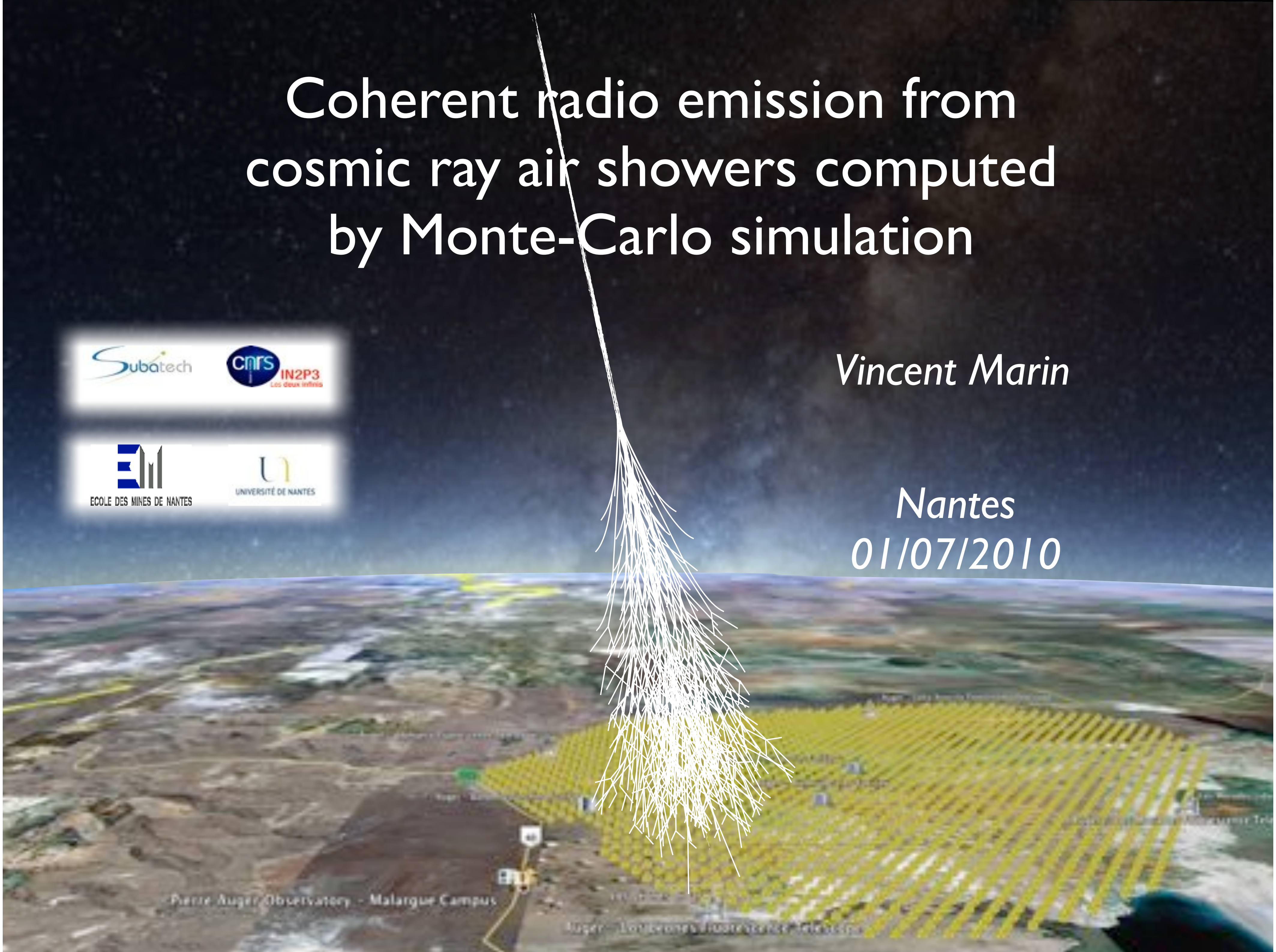
Coherent radio emission from cosmic ray air showers computed by Monte-Carlo simulation

Vincent Marin

Nantes
01/07/2010

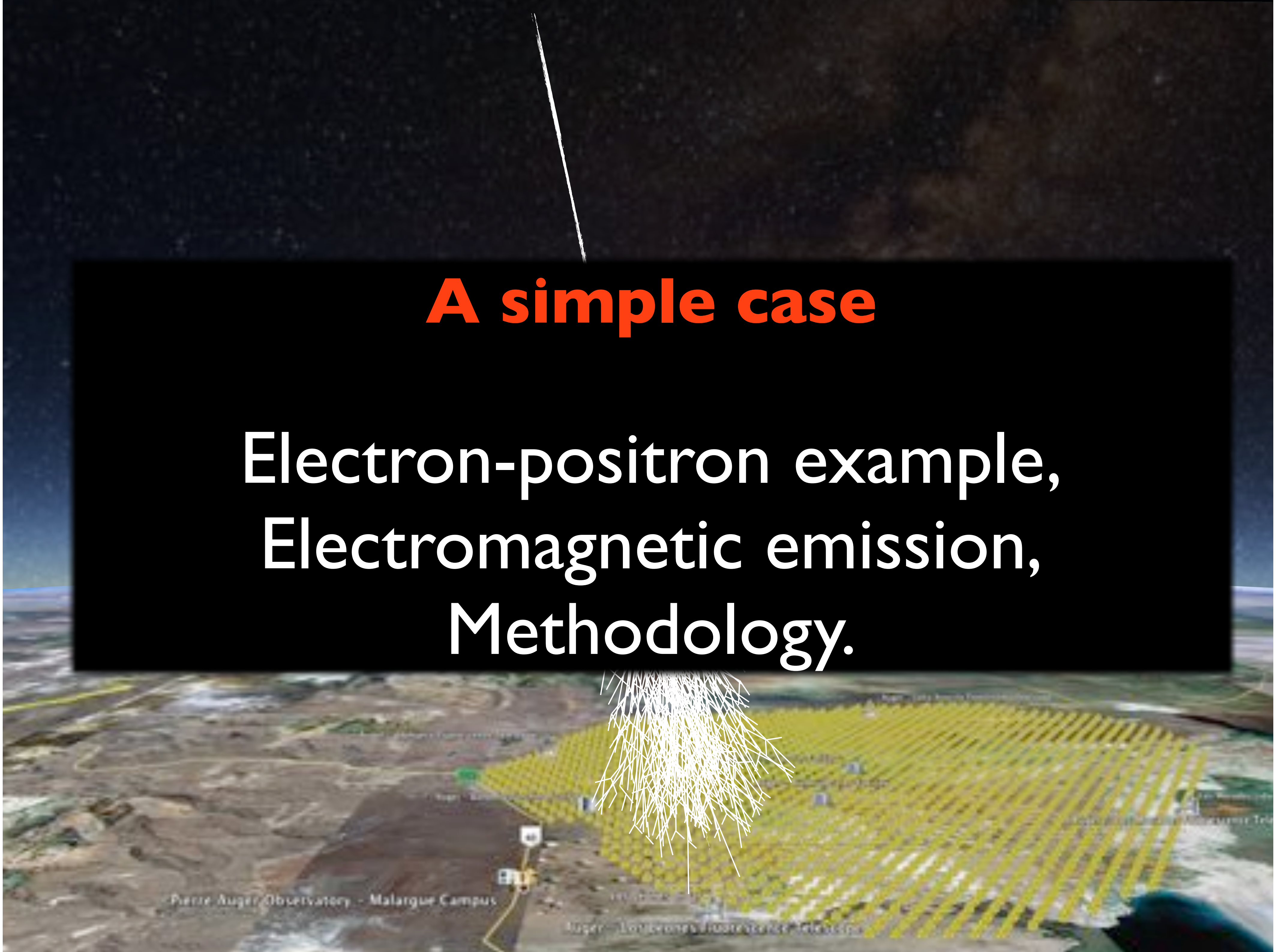


A simple case

Electron-positron example,
Electromagnetic emission,
Methodology.

Application to air shower

Geometrical description,
Monte-Carlo simulation,
First results and analysis,
Conclusion.



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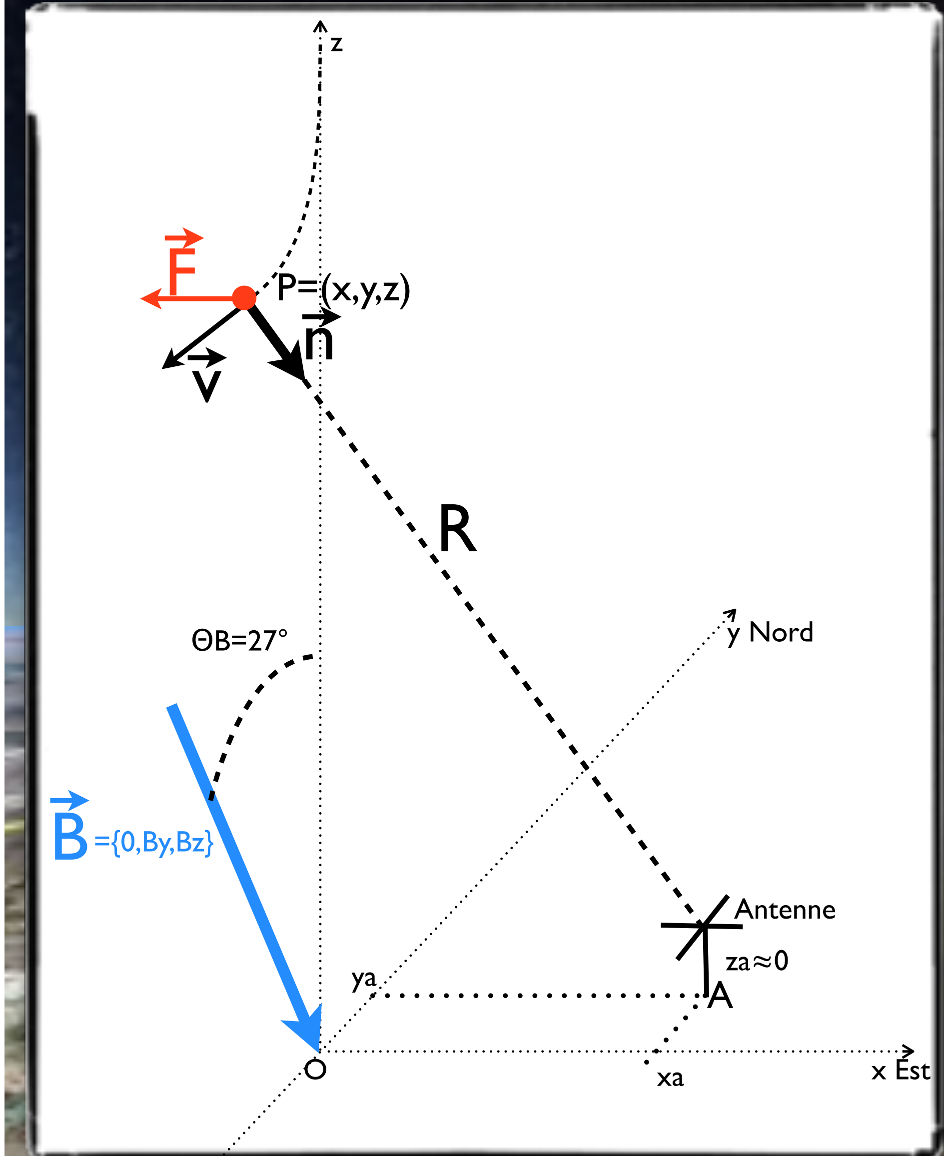
Simple case

Electron-positron pair



$$\frac{\mathrm{d}\vec{\beta}}{\mathrm{d}t} = \frac{e}{\gamma \mathrm{mc}} \vec{\beta} \wedge \vec{B}$$

Motion in the geomagnetic field

One mean free path 36.62 g cm^2

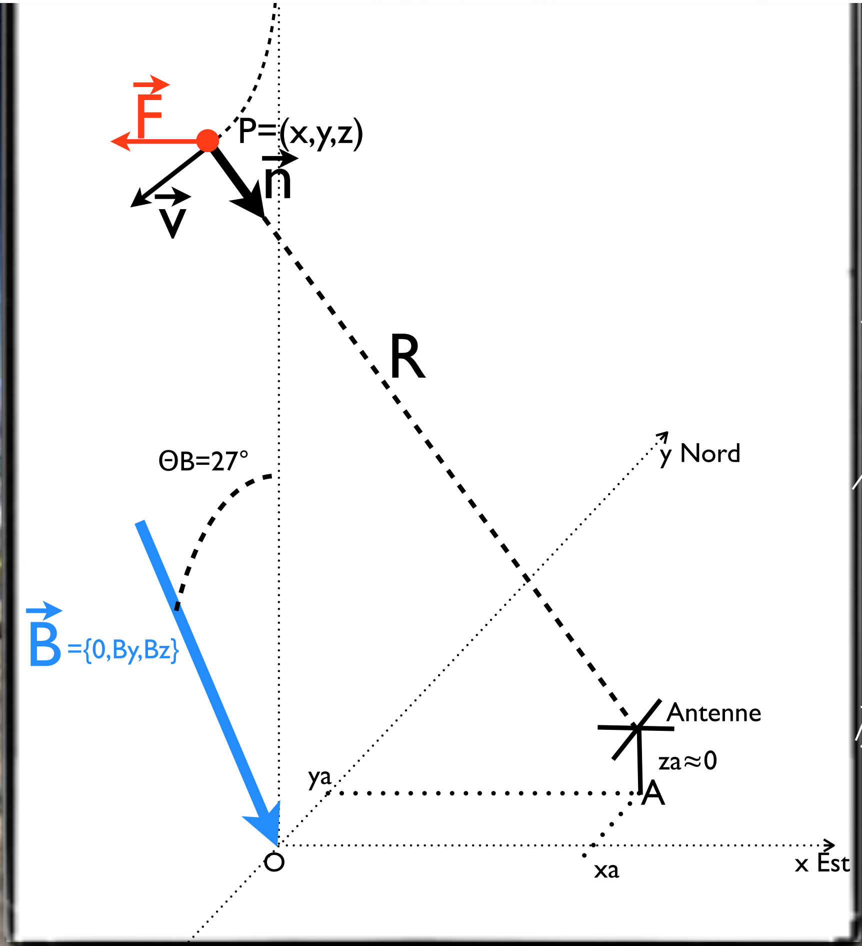
The trajectory of each particle is divided into small segments to compute energy losses

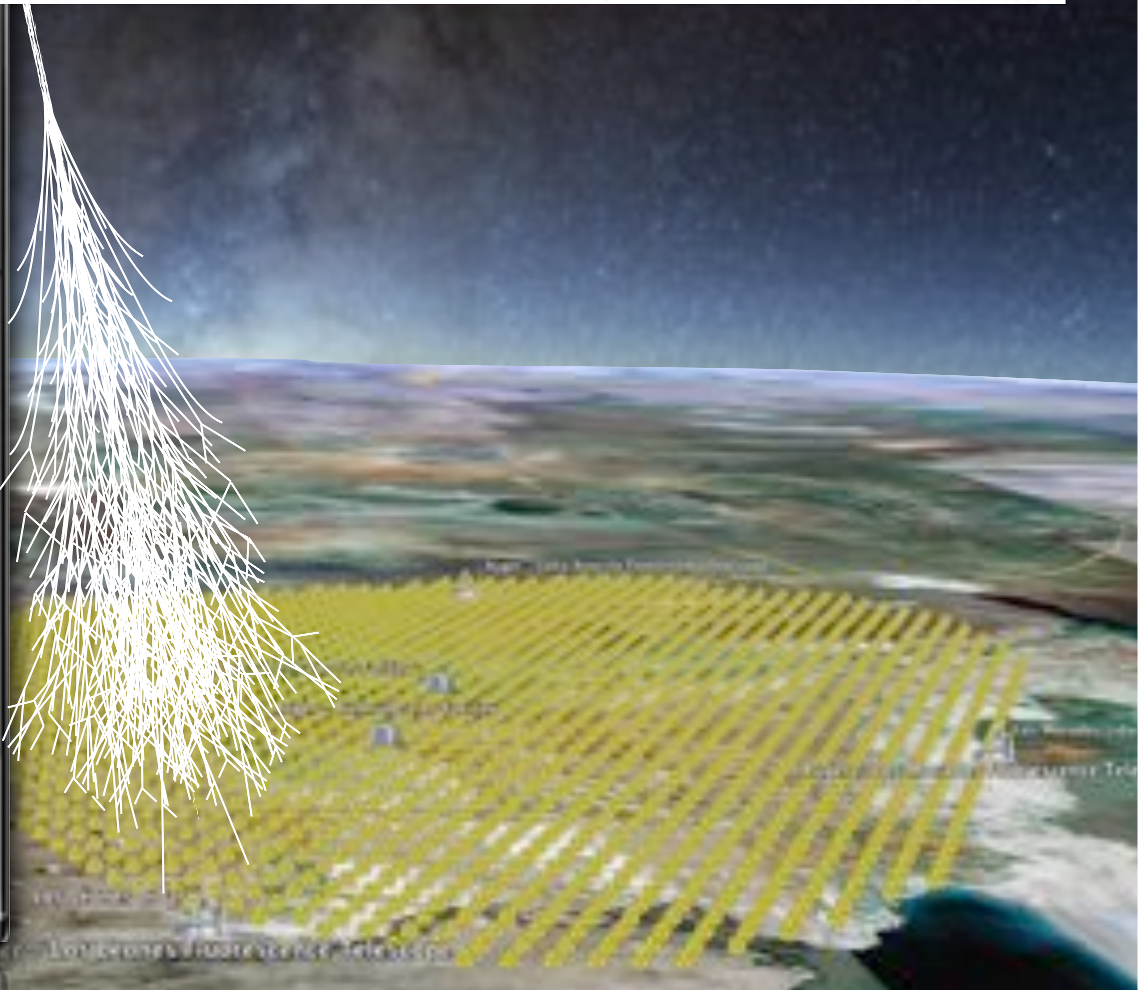
Scattering not included for the moment

Electric field

Electric field emitted by relativistic particles

$$\vec{E}(A,t) = \frac{q}{4\pi\epsilon_0}\left(\left[\frac{\vec{n}-\vec{\beta}}{\gamma^2\left(1-\vec{\beta}.\vec{n}\right)^3 R^2}\right] + \frac{1}{c}\left[\frac{\vec{n}\wedge\left\{\left(\vec{n}-\vec{\beta}\right)\wedge\dot{\vec{\beta}}\right\}}{\left(1-\vec{\beta}.\vec{n}\right)^3 R}\right]\right)_{\text{retardé}}$$





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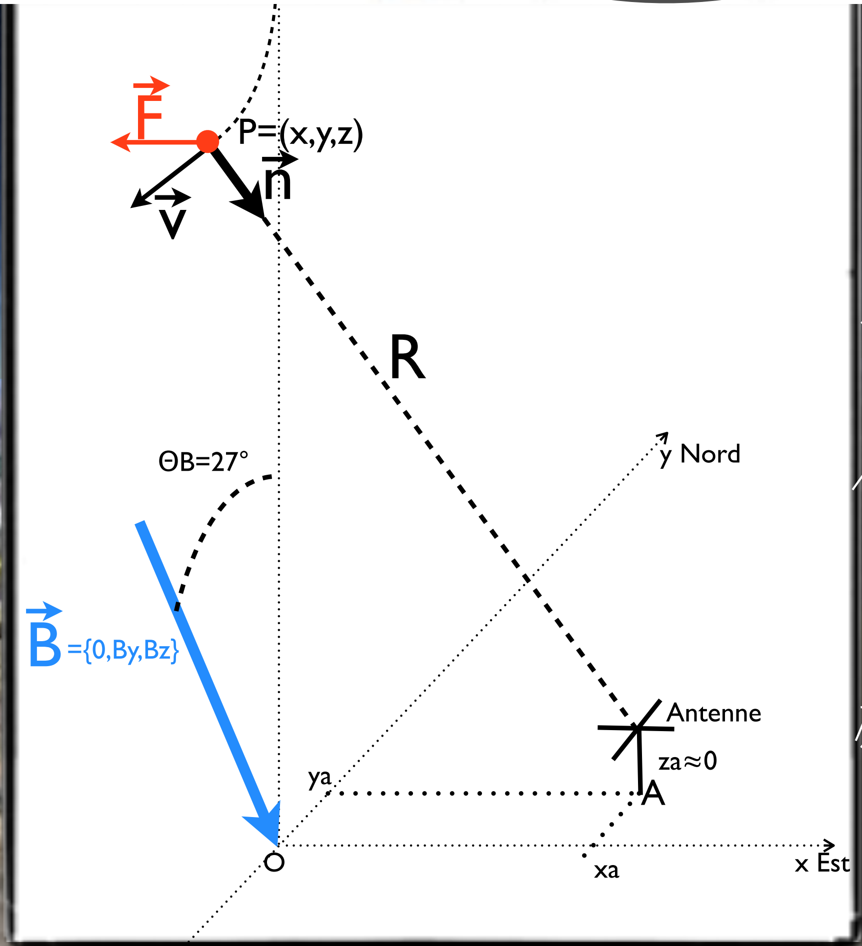
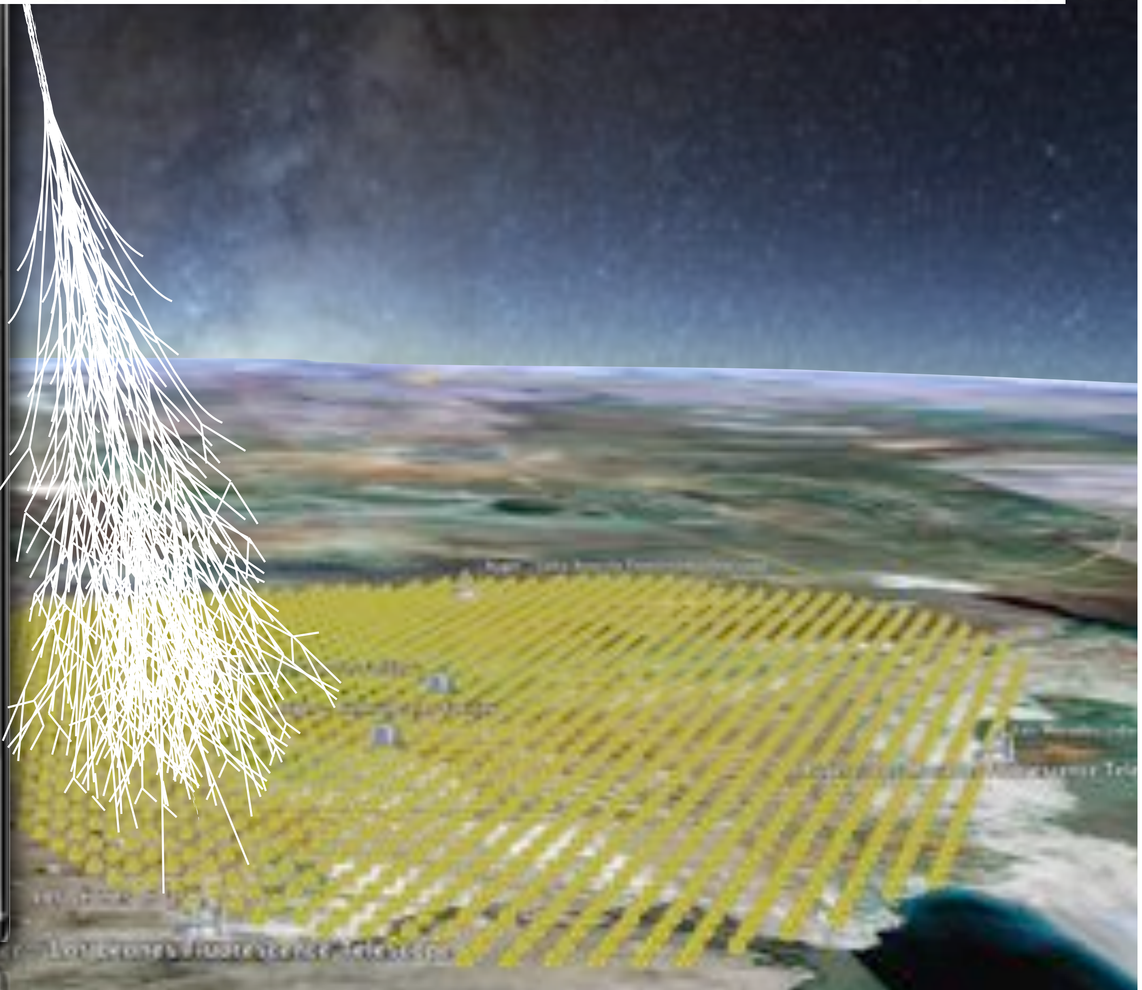
Coulombian part
Neglected





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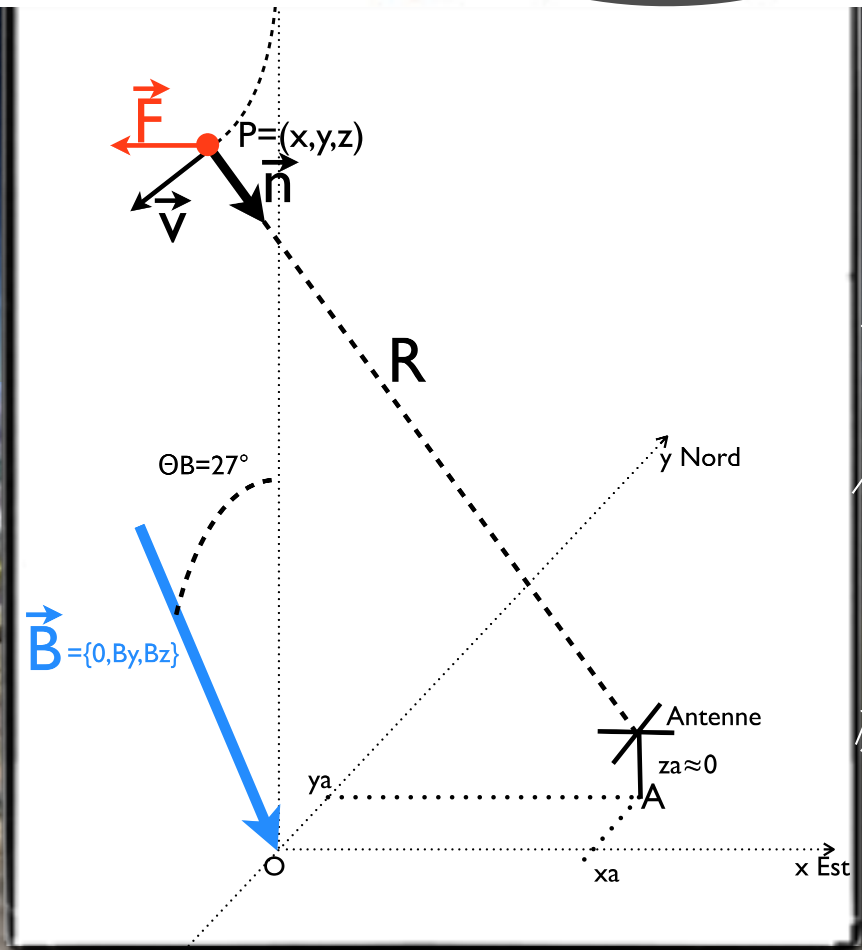

- $\dot{\vec{\beta}}$ Acceleration
- $\vec{\beta}$ Velocity
- $\overrightarrow{OP}$ Position
- R Part-ant distance
- $\vec{n}$ Part-ant vector

Electric field

Electric field emitted by relativistic particles

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Coulombian part Neglected

delayed time for reception

$t_{reception} = t_{emission} + R/c$

To avoid time consuming procedure of signal interpolation for each reception time bin, we solve:

$t_{reception} = f(t_{emission})$

to obtain $t_{emission} = f(t_{reception})$

- $\dot{\vec{\beta}}$ Acceleration
- $\vec{\beta}$ Velocity
- $\overrightarrow{OP}$ Position
- R Part-ant distance
- $\vec{n}$ Part-ant vector

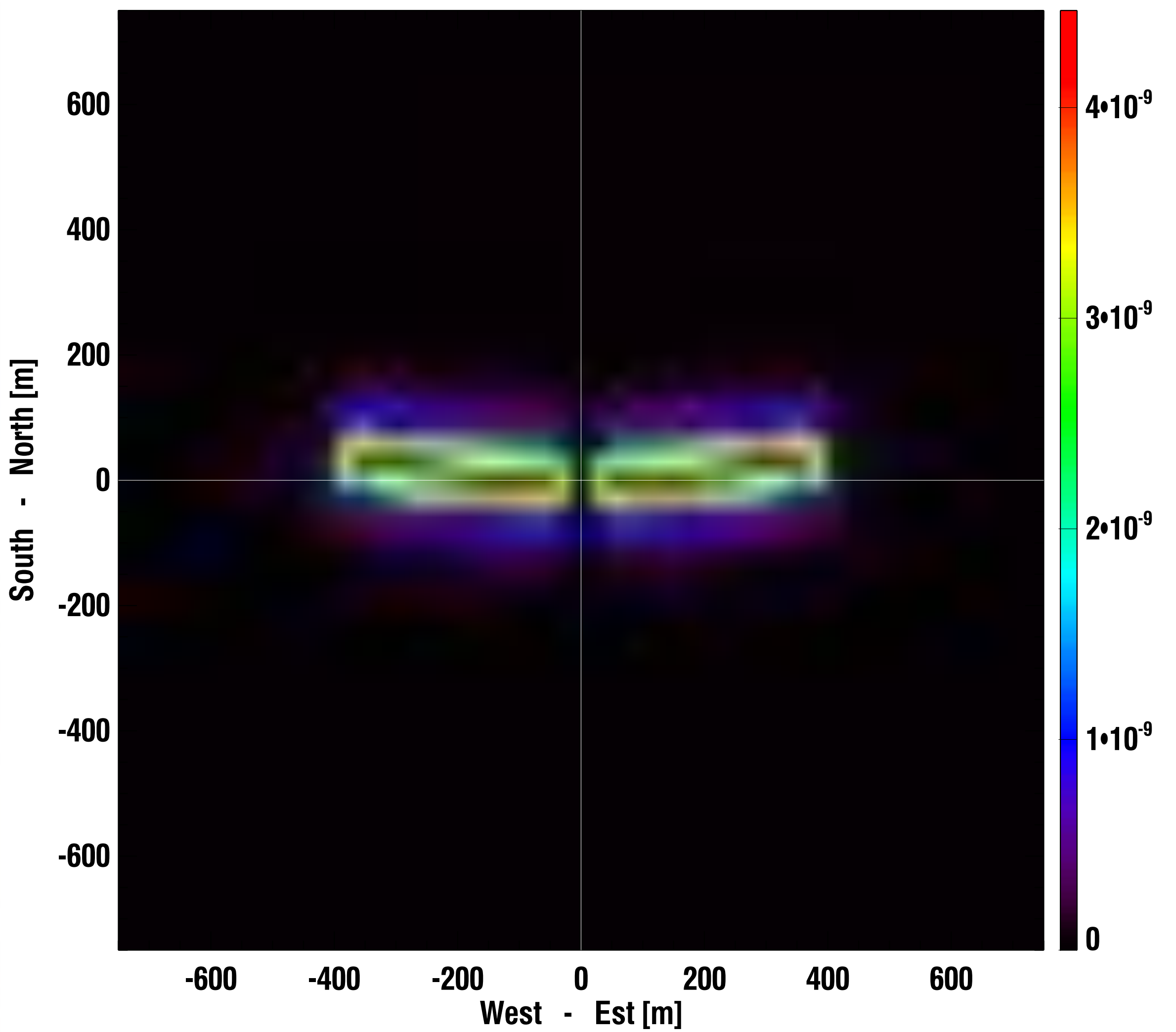
Electron-positron pair example

Ground footprint of Max $|E_{EW}(t)|$

generated by electron/positron pair

initially injected in (0,0,4000 m)
vertical initial velocity p= 30 MeV
travel length : 1500 m

EW component of the electric field emitted by an electron-positron pair



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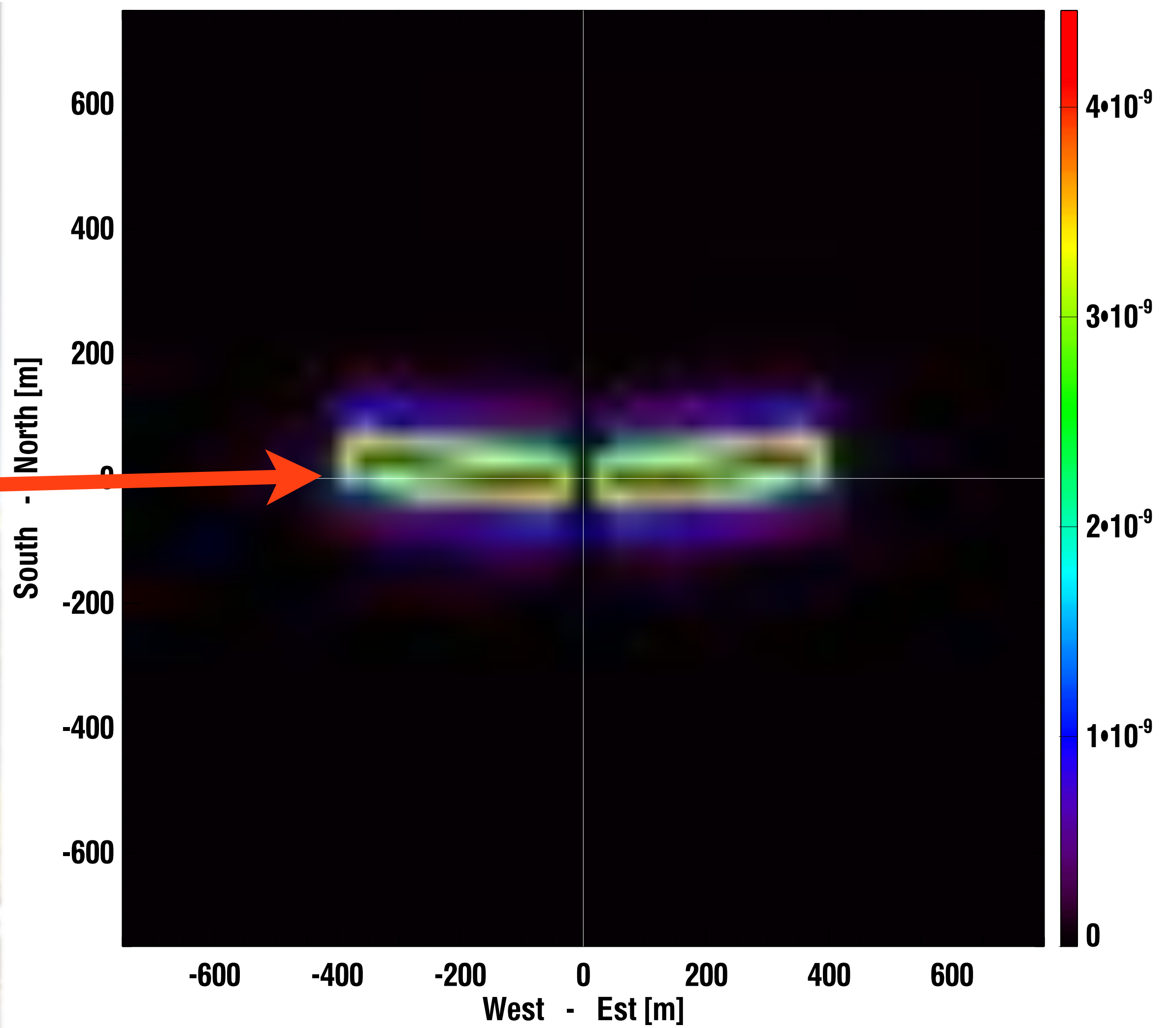
Narrow band

Synchrotron radiation strongly confined in a emission cone.
Used to accelerate computations.

EW component of the electric field emitted by an electron-positron pair



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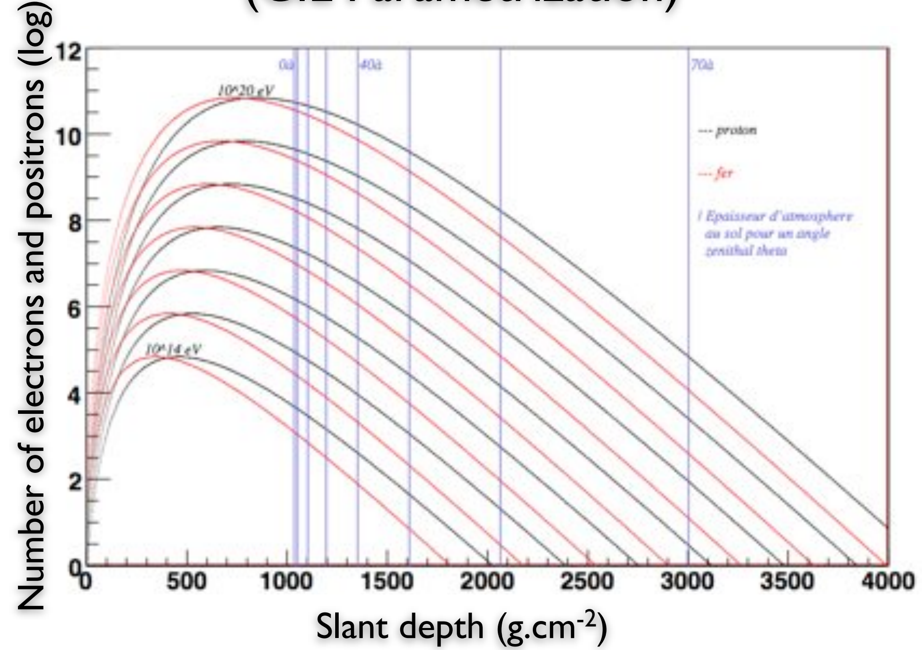
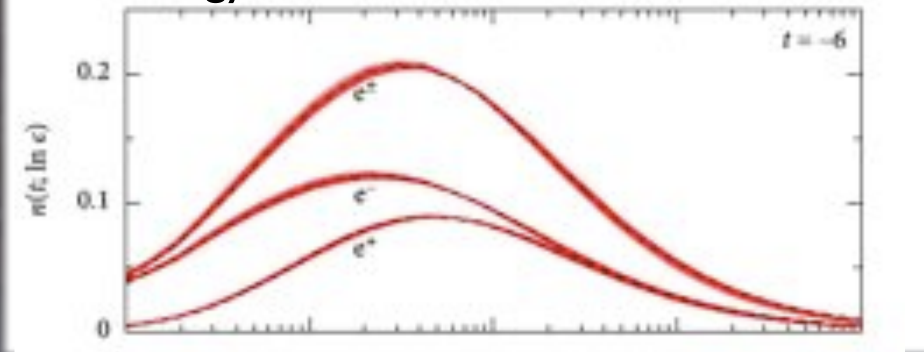
Air shower geometrical description

What we need :

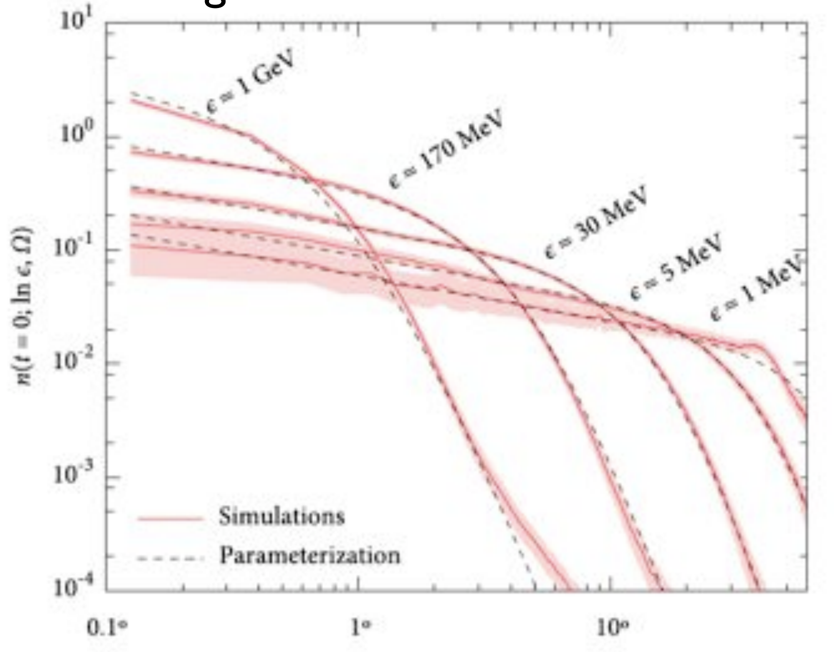
Longitudinal development (GIL Parametrization)



Energy distribution

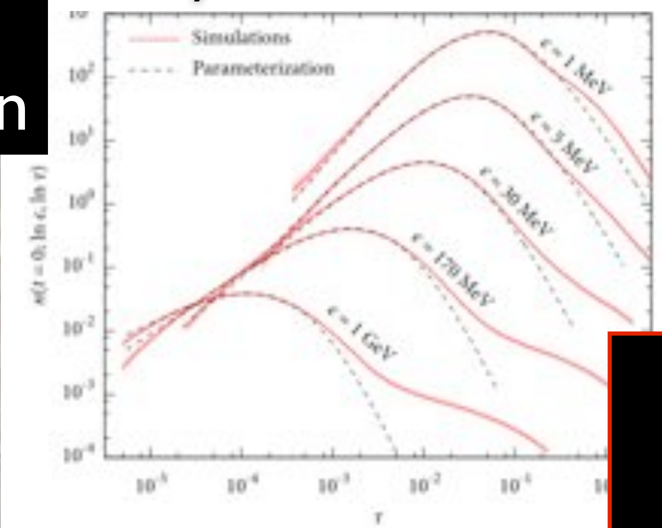


Angular distribution



Pancake description

Delay time distribution



Well described in :
arXiv:0902.0548v1 Lafebre et al

Air shower geometrical description

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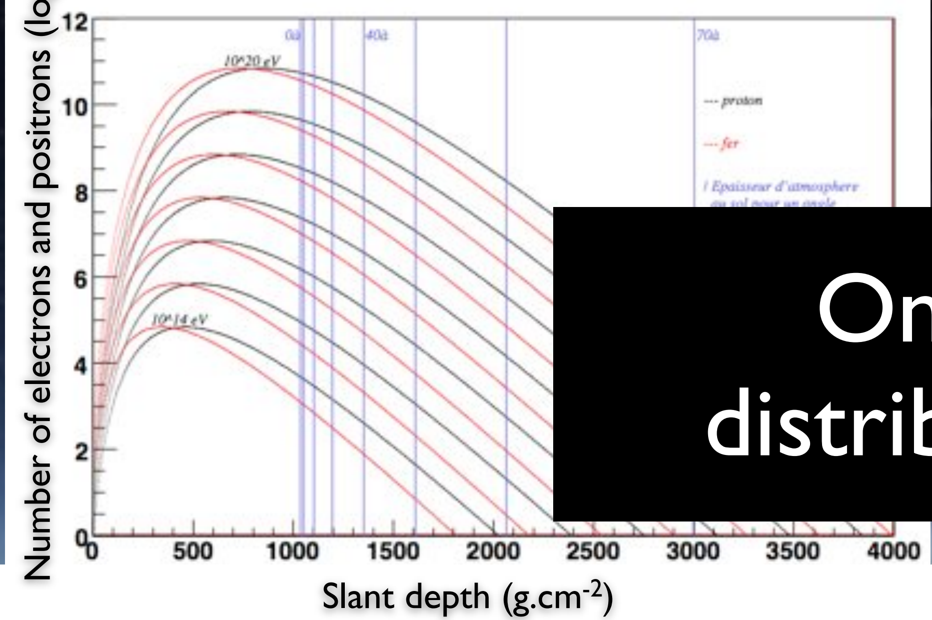
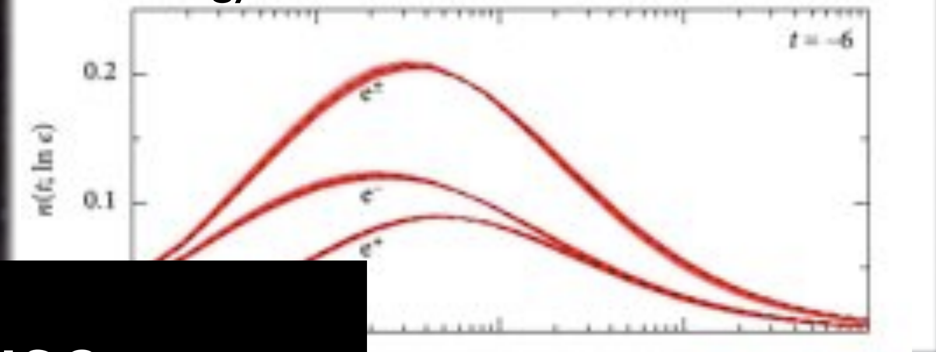
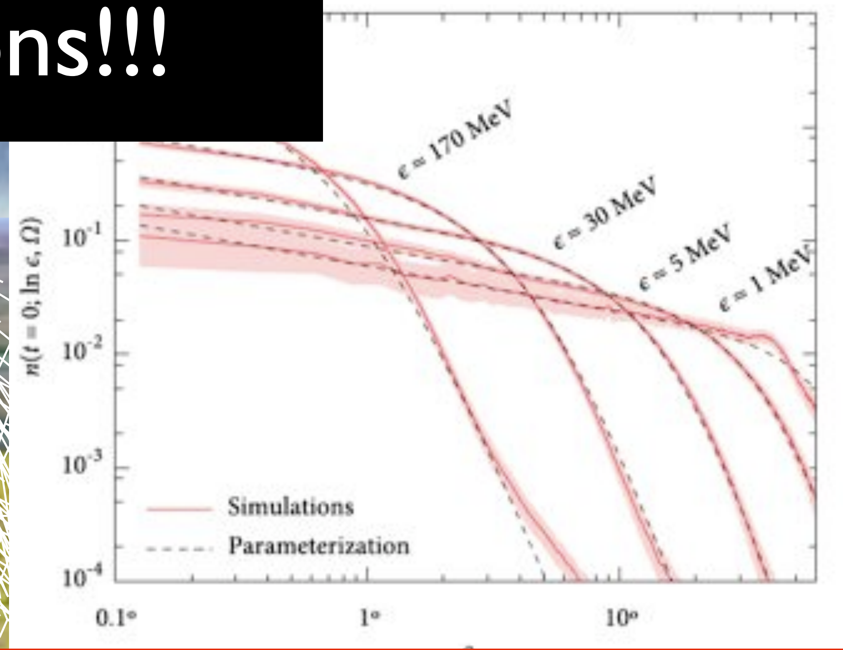


Energy distribution



Only use distributions!!!

distribution



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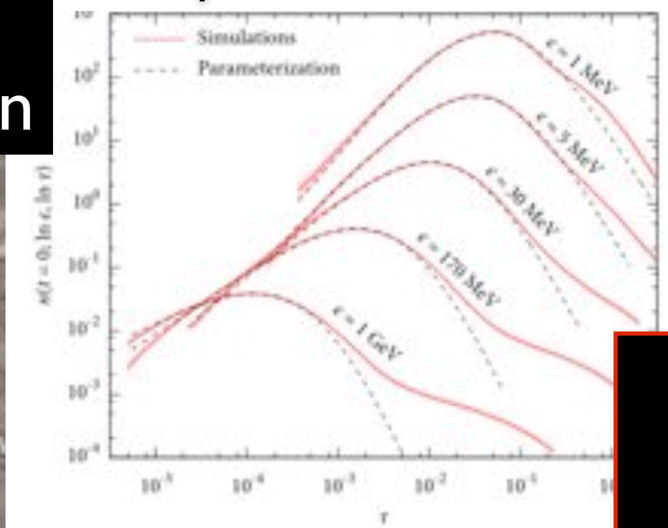

Well described in :
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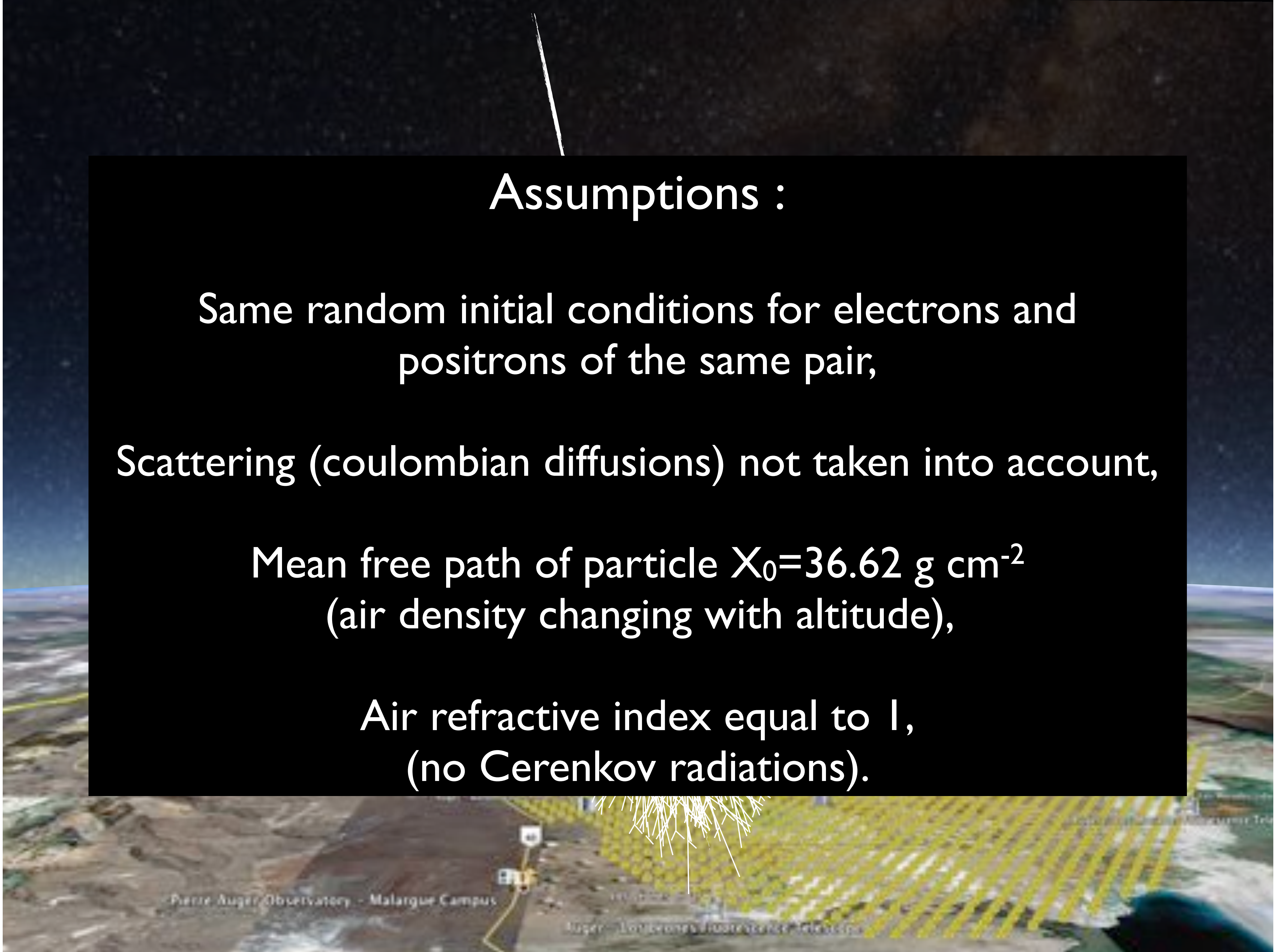
Assumptions :

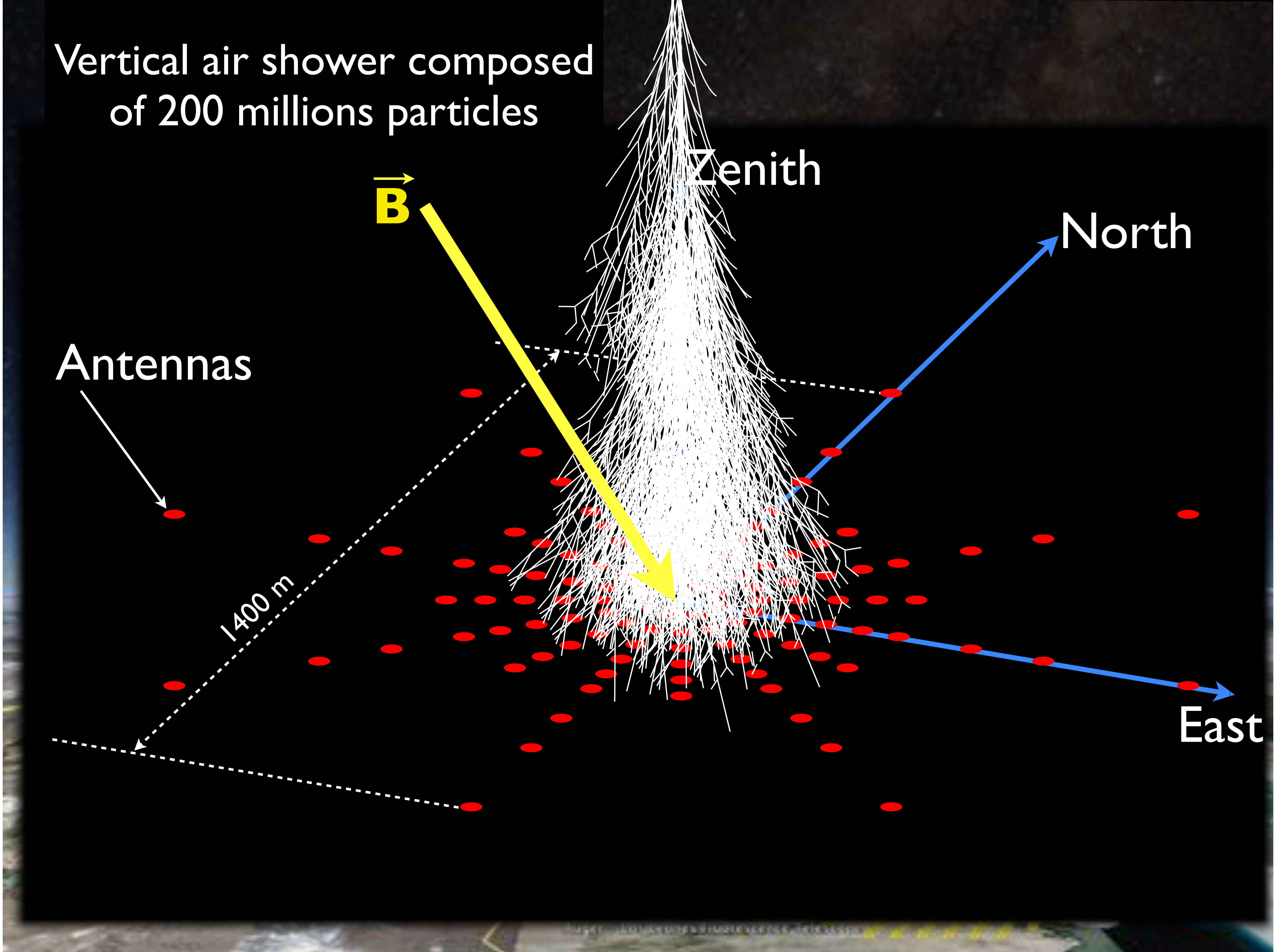
Same random initial conditions for electrons and positrons of the same pair,

Scattering (coulombian diffusions) not taken into account,

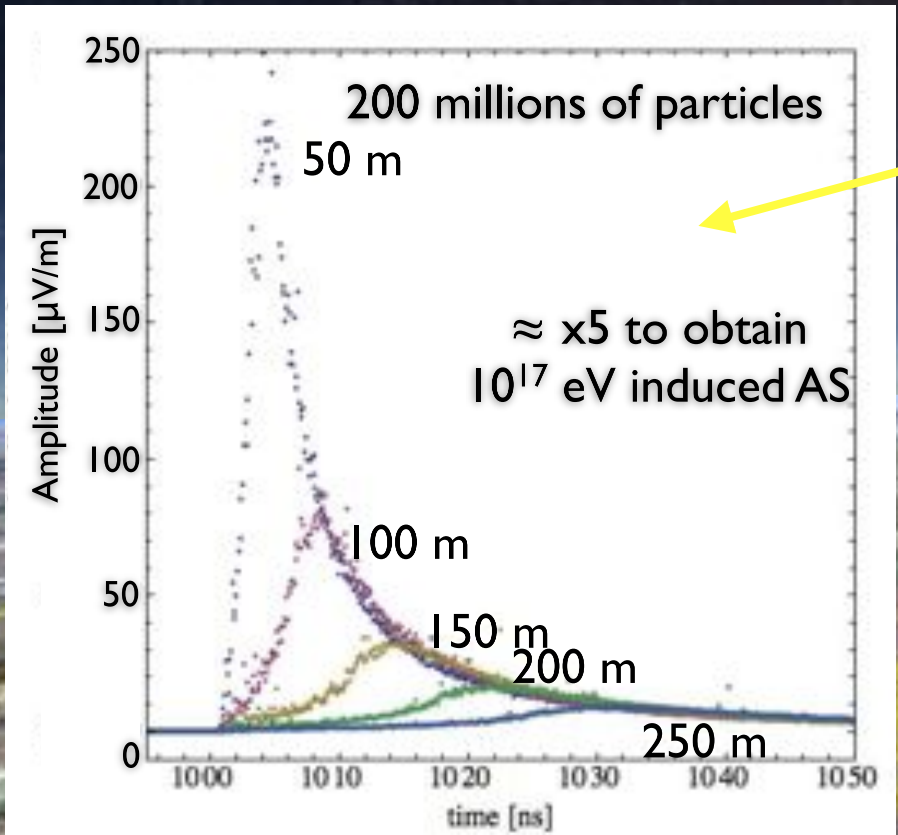
Mean free path of particle X_0=36.62 g cm^{-2} (air density changing with altitude),

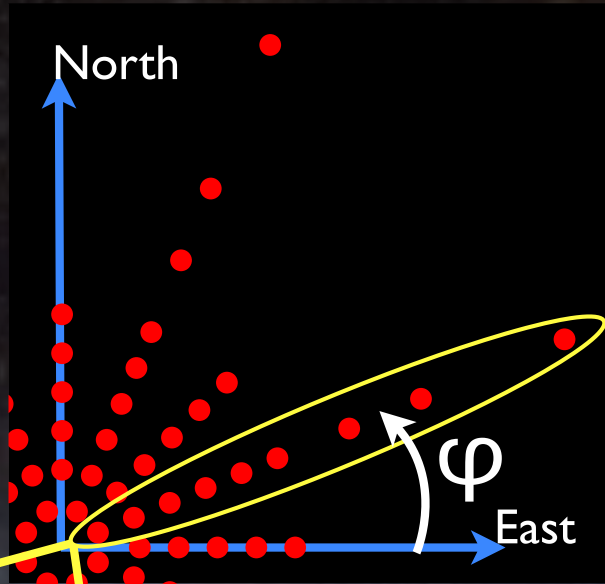
Air refractive index equal to 1, (no Cerenkov radiations).

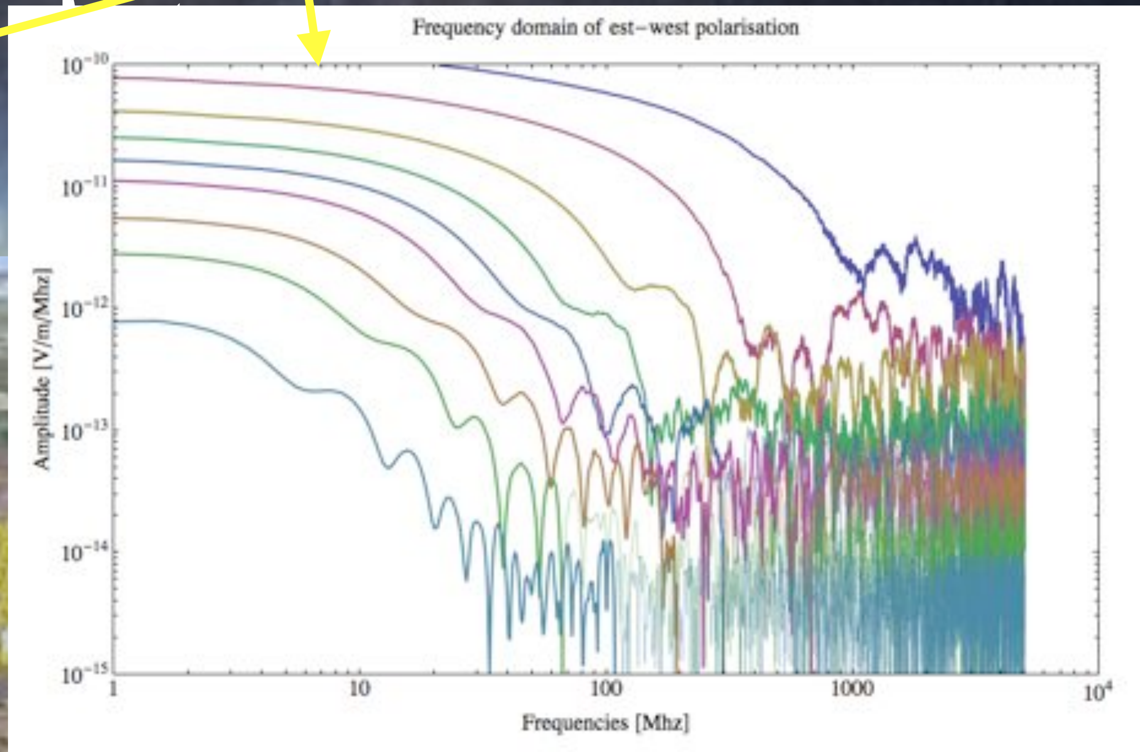



Vertical air shower composed of 200 millions particles
Zenith
B
North
Antennas
1400 m
East

Different impulsions for different distances from air shower axis:



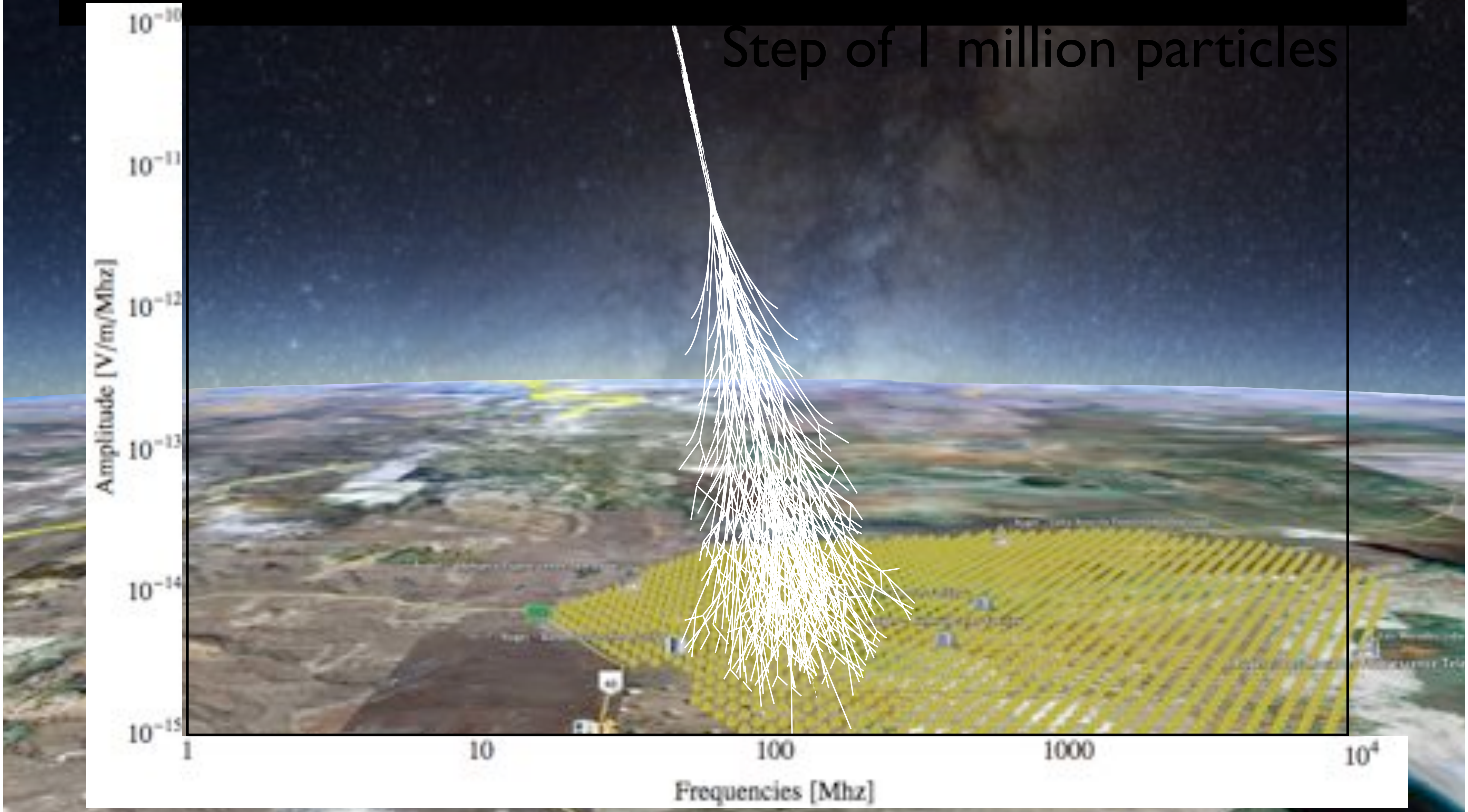




Analysis

Power deposited in function of particles number:

Evolution of spectra with particles number,
from 1 million to 200 millions.



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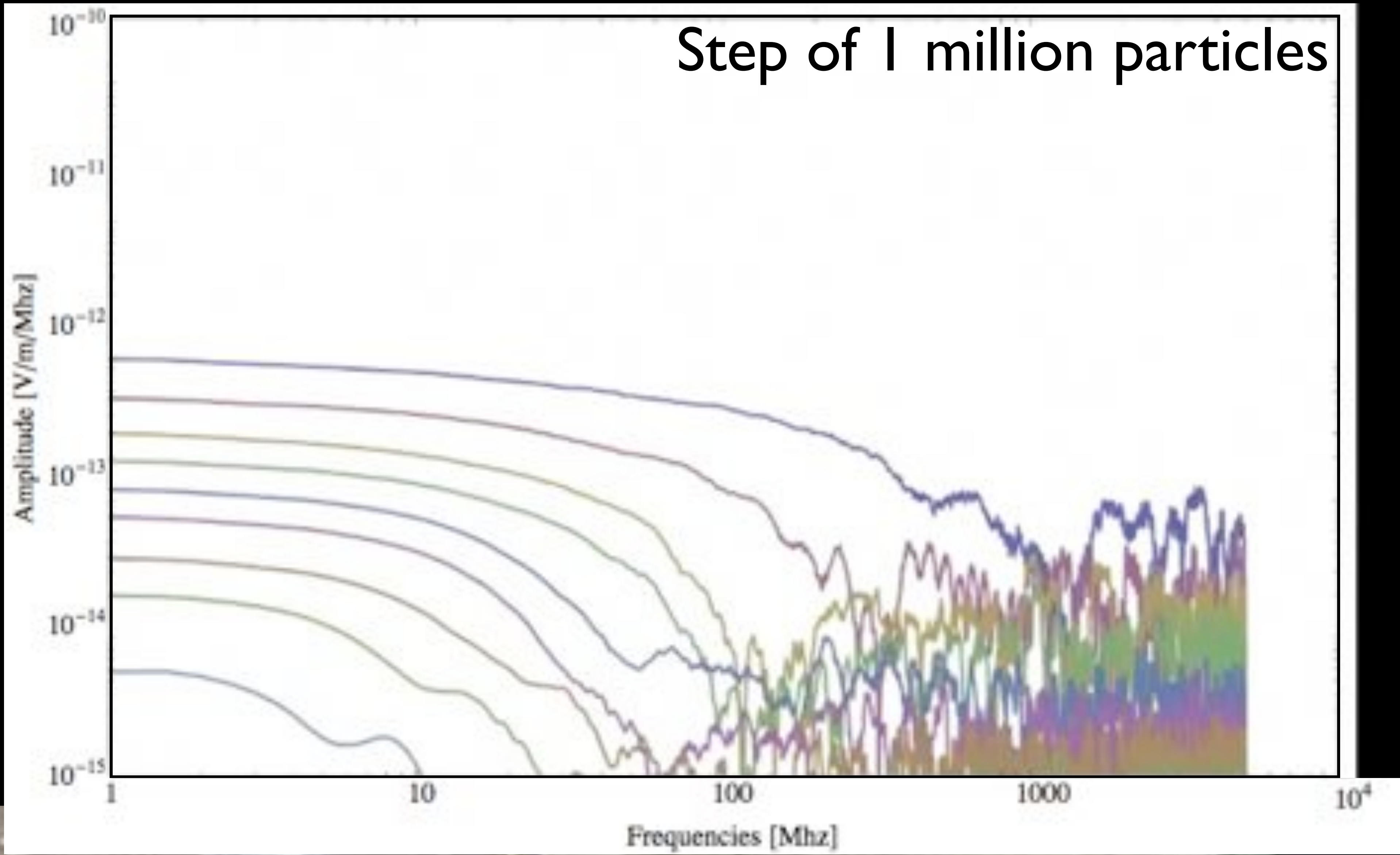
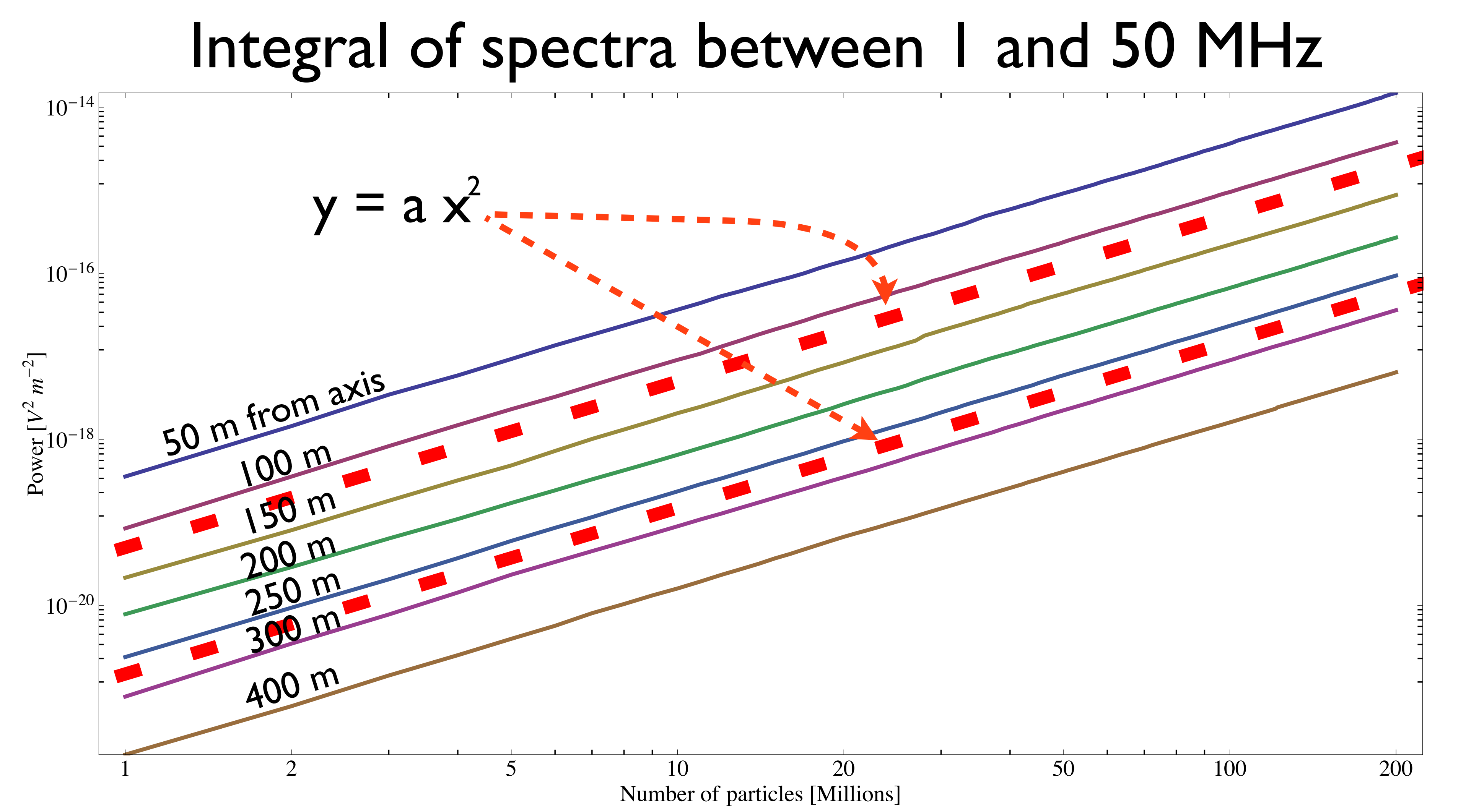


Analysis



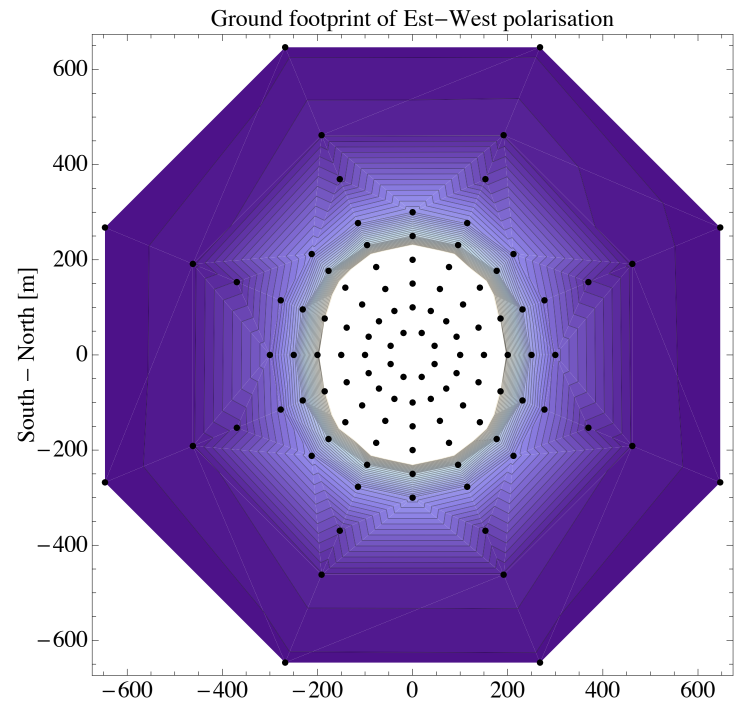
This behavior could give us directly a theoretical law between primary energy and signal observed.

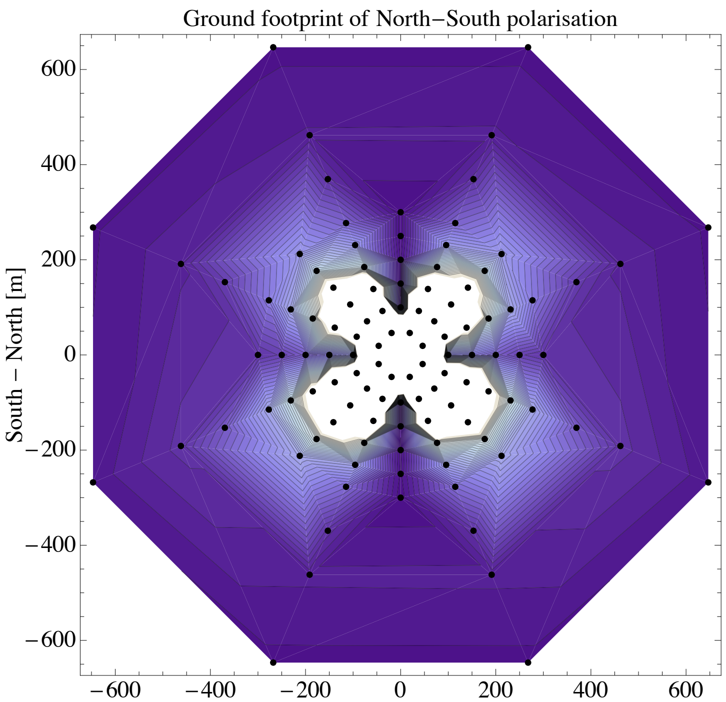
Ground footprint

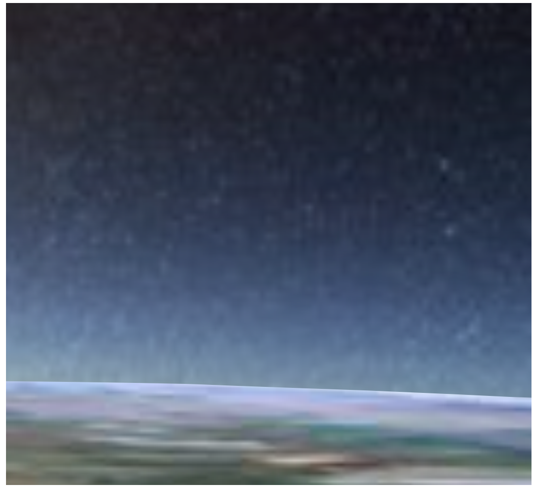
East-West polarisation

North-South polarisation

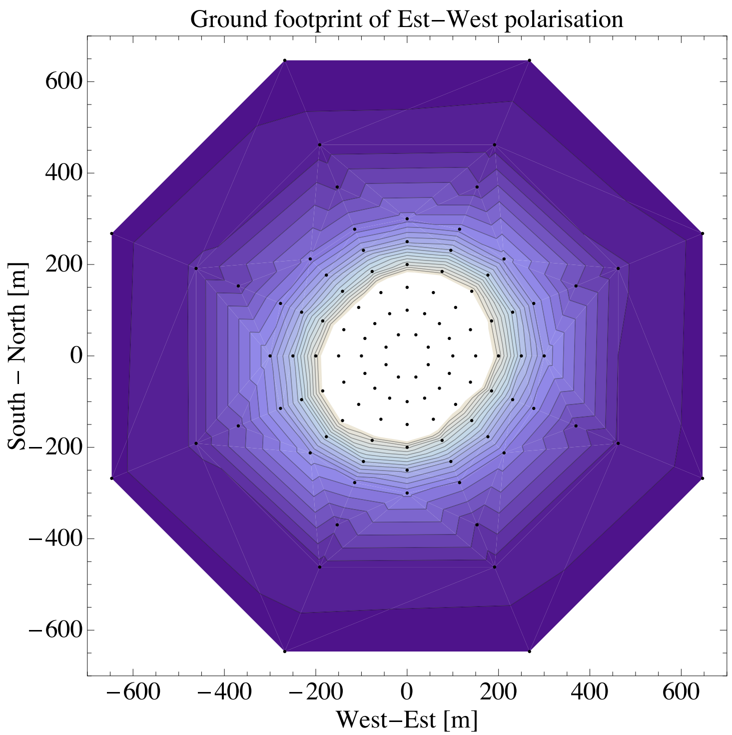
Vertical AS
θ=0° φ=0°

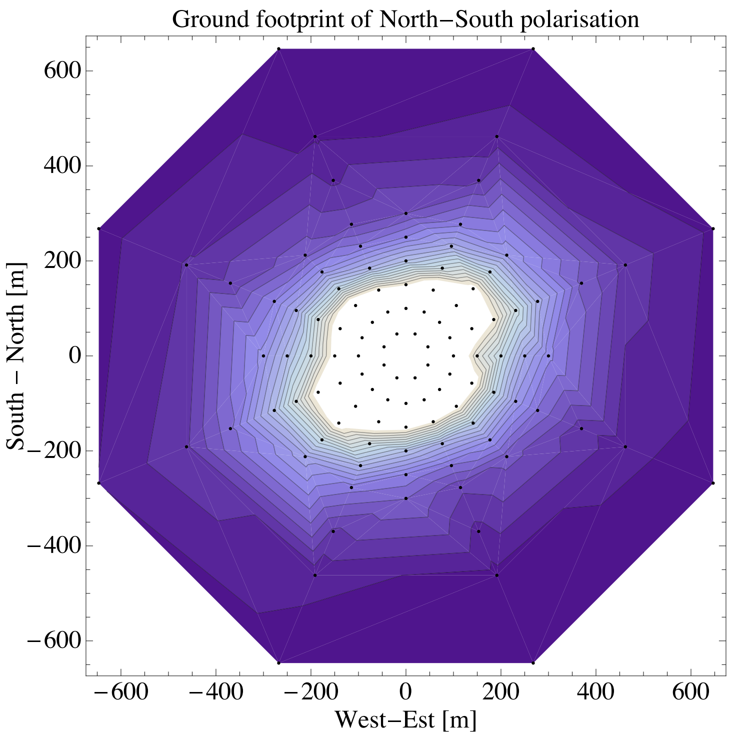




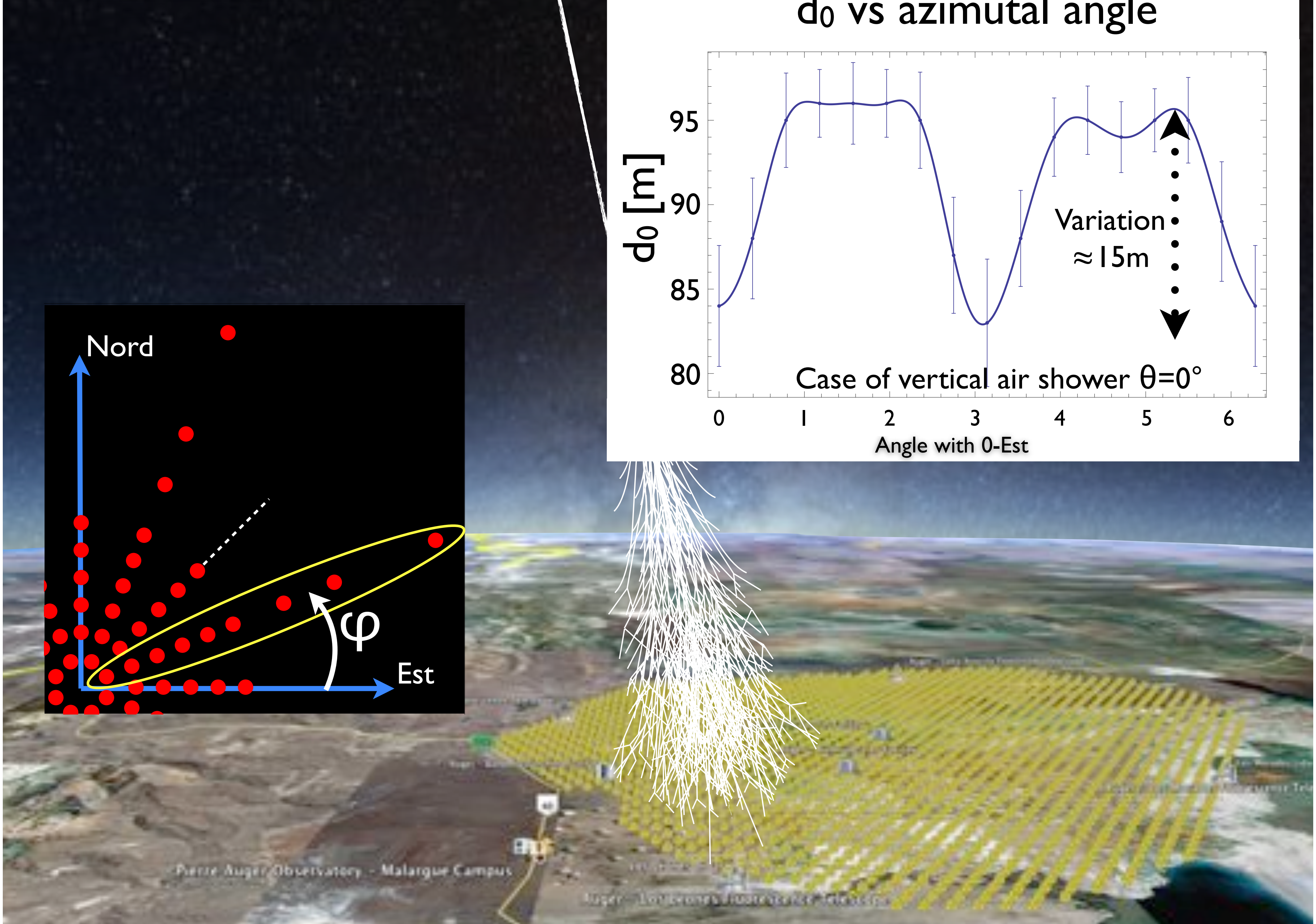


Inclined AS
θ=40° φ=45°





First Analysis



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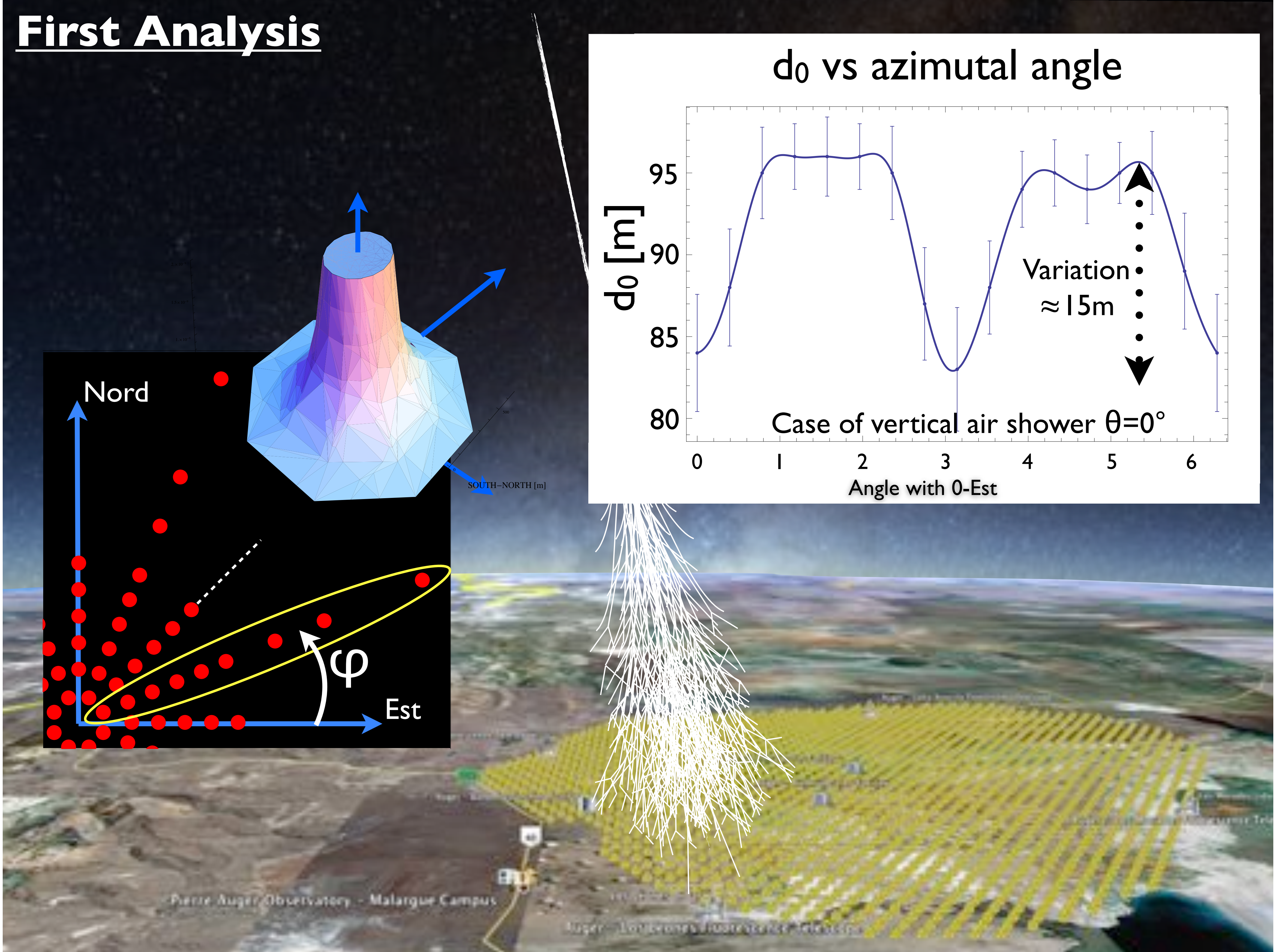

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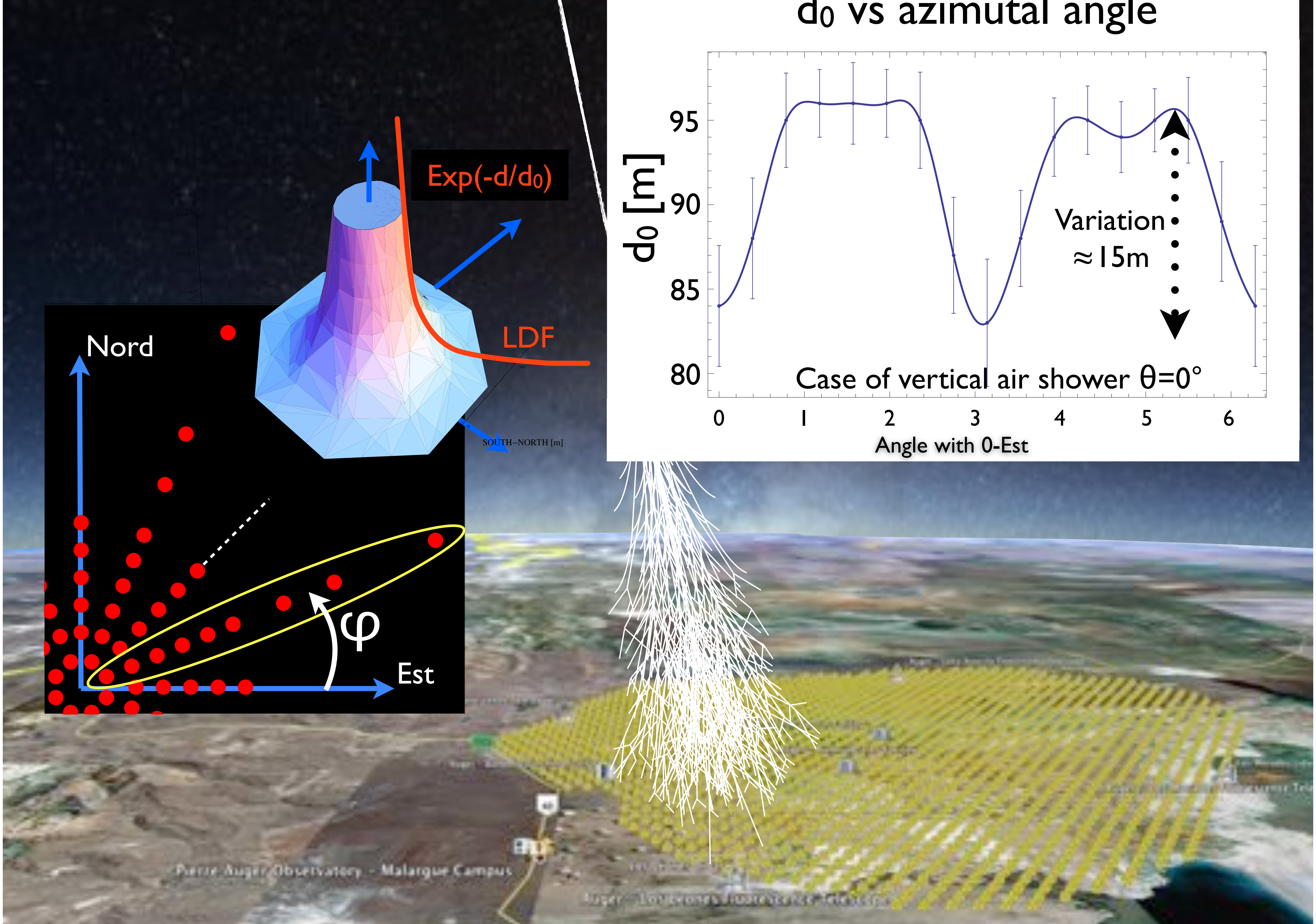

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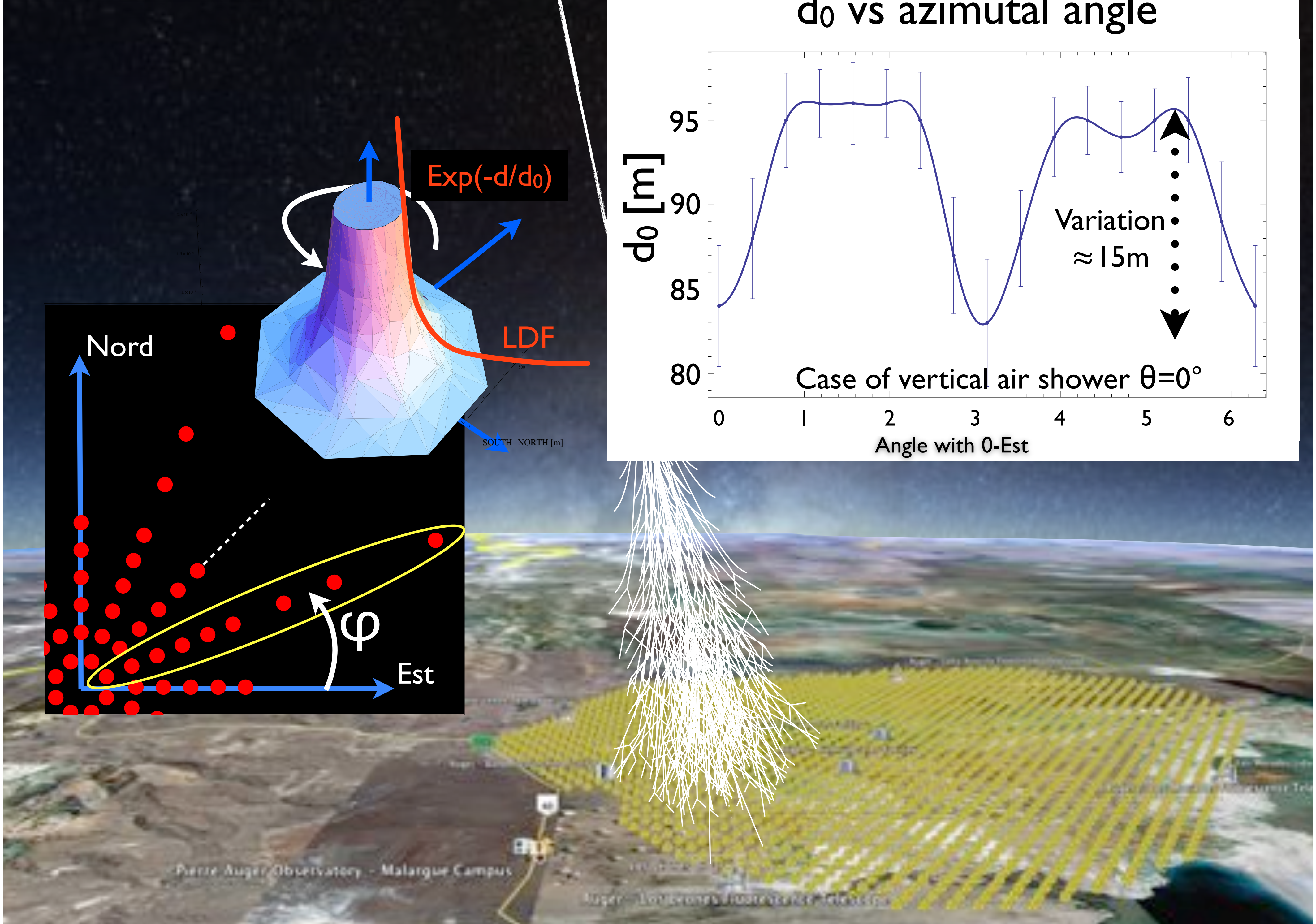

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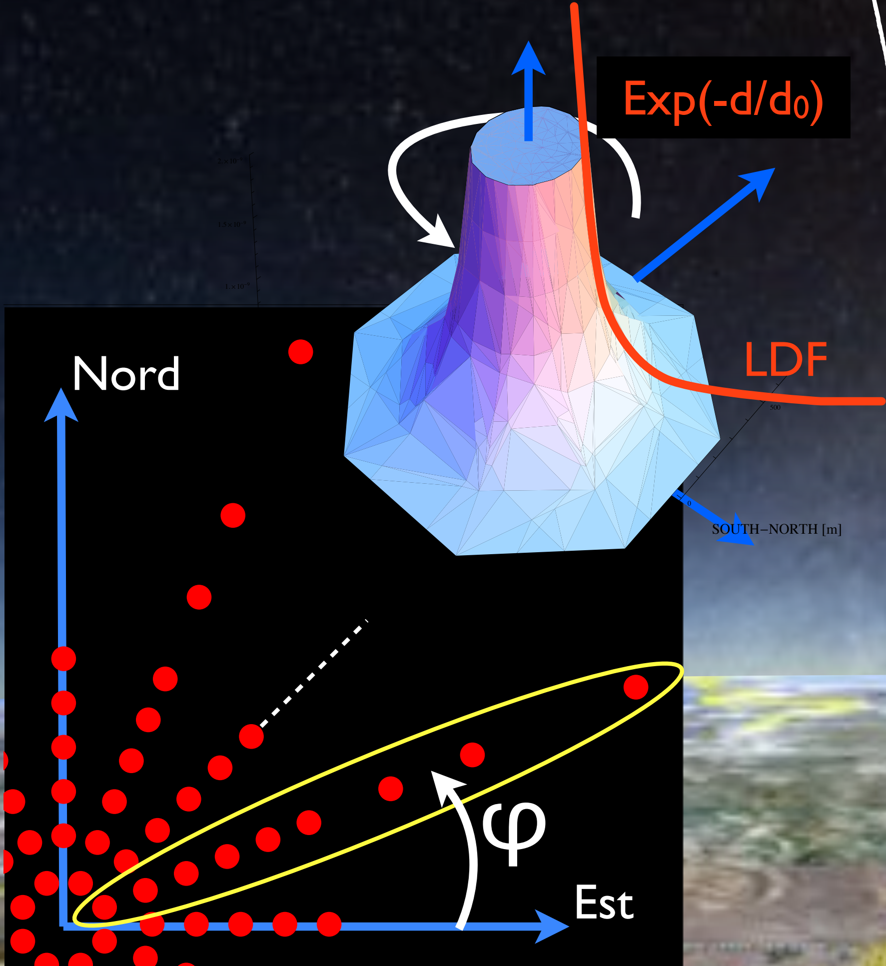

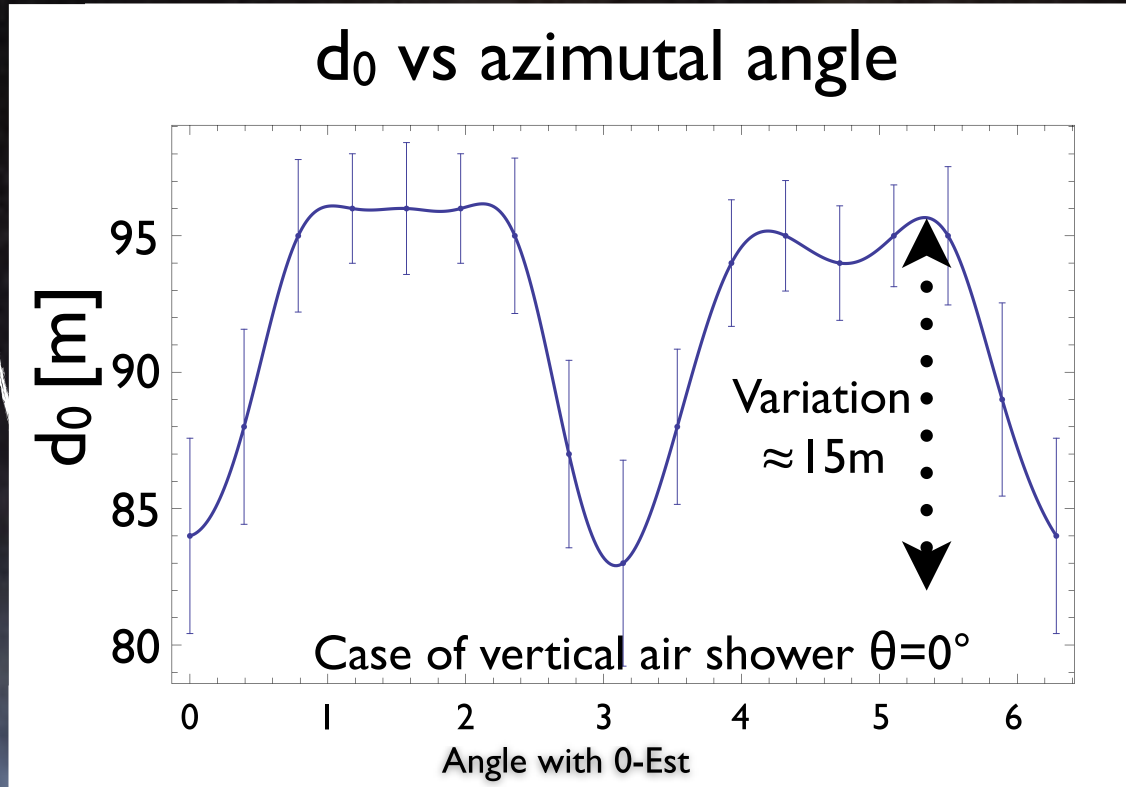

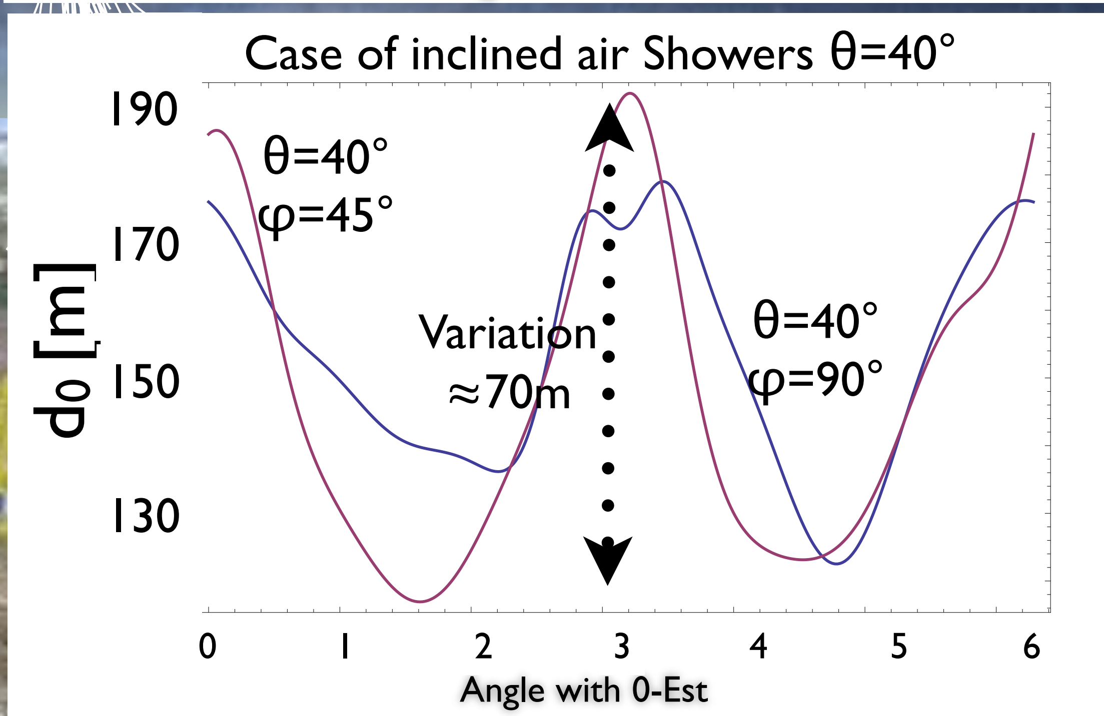

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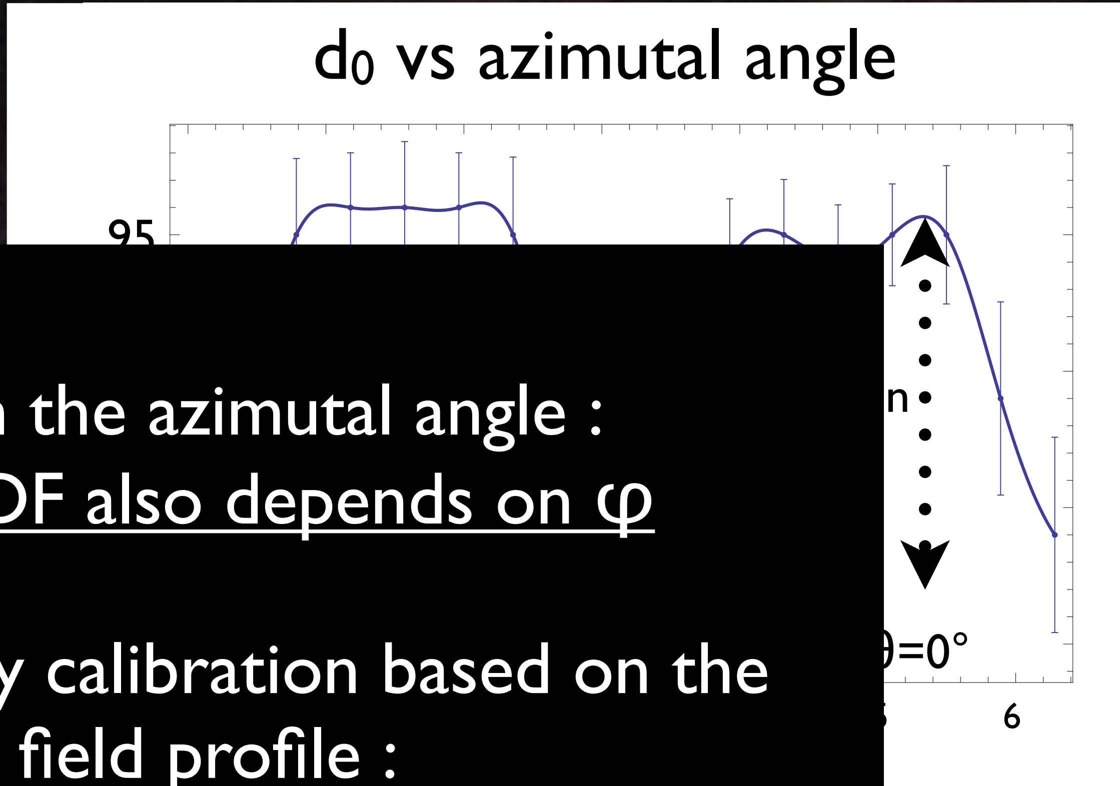
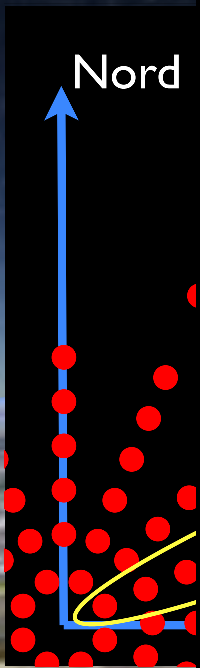




d_0 depends on the azimutal angle :

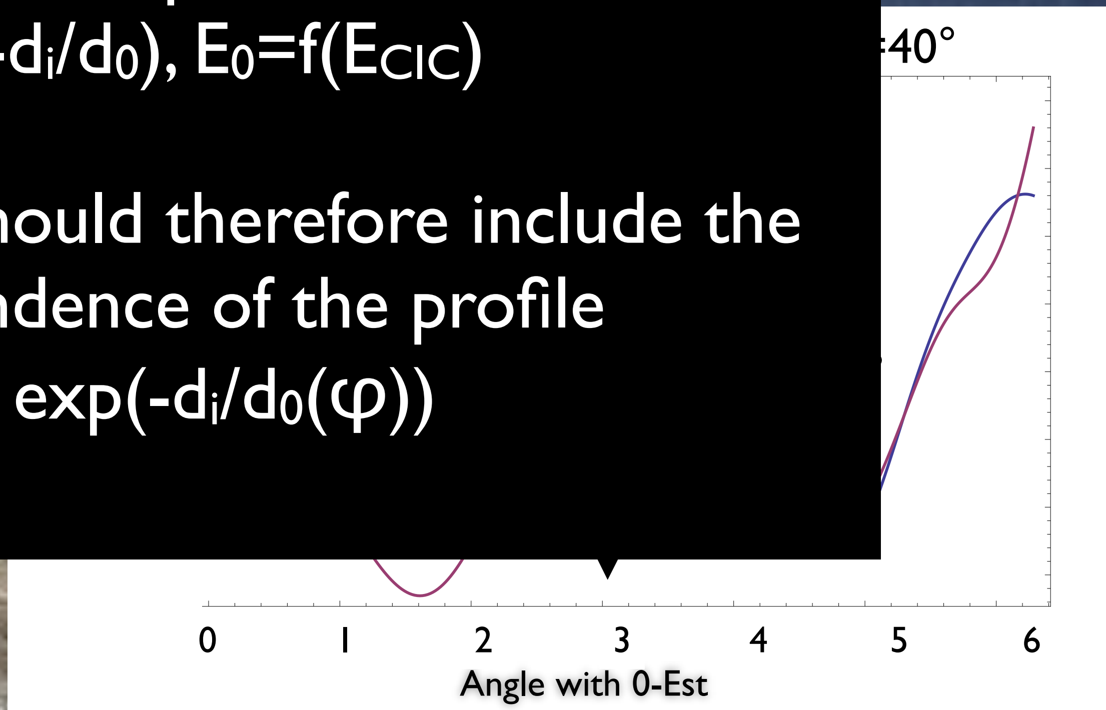
$d_0(\varphi)$ → LDF also depends on φ

CODALEMA energy calibration based on the electric field profile :

$E_i = E_0 \exp(-d_i/d_0)$, $E_0 = f(E_{CIC})$

Energy estimation should therefore include the azimutal dependence of the profile

$E_i = E_0(\varphi) \exp(-d_i/d_0(\varphi))$



Conclusion

Strategy adopted for computation allows a large number of particles without excessive effort :

for one antenna => 1 million of particles in 7 min (2.66 GHz intel)

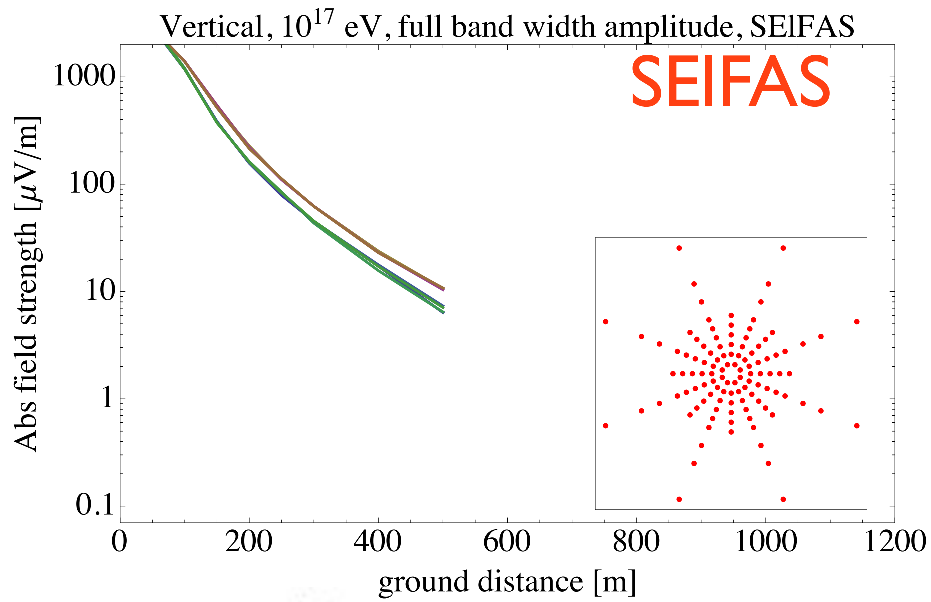
The code «SEIFAS» is written in C and could be shared soon
SEIFAS=Simulation Electric Field Air Shower

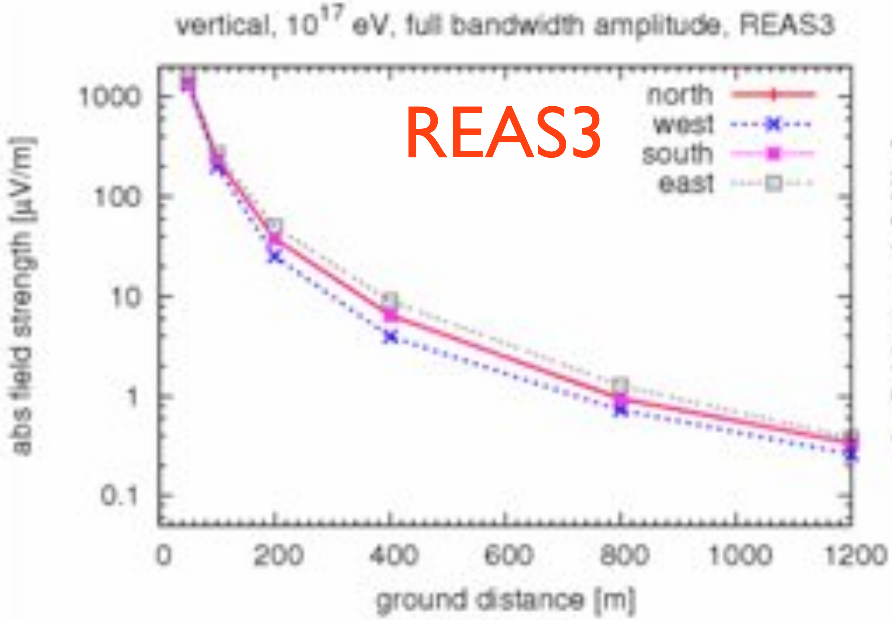
Work on the analysis of results given by the simulation in particular:

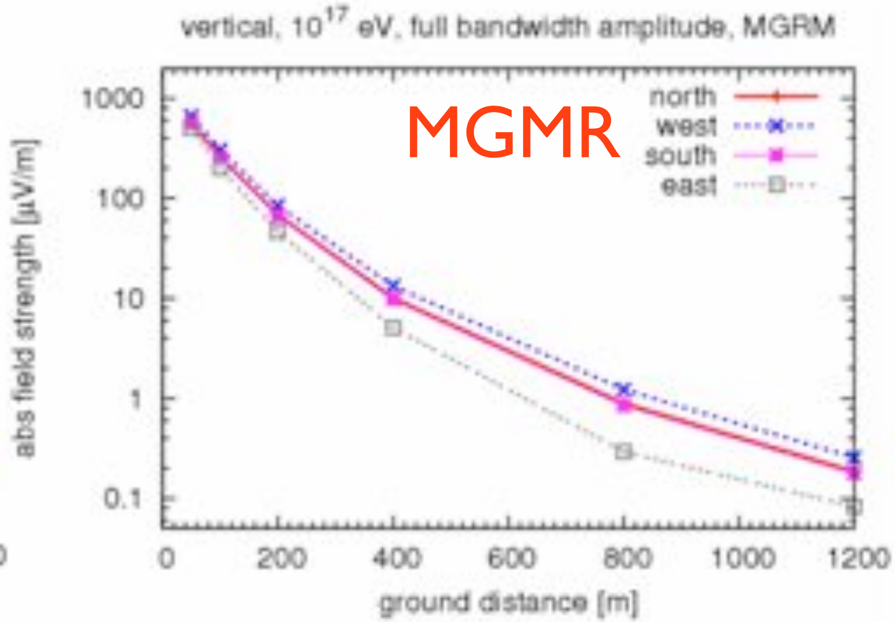
Comparison with other models like REAS and MGRM...

Conclusion

Nancay
magnetic field
B=0.50 Gauss
θ=27°
→





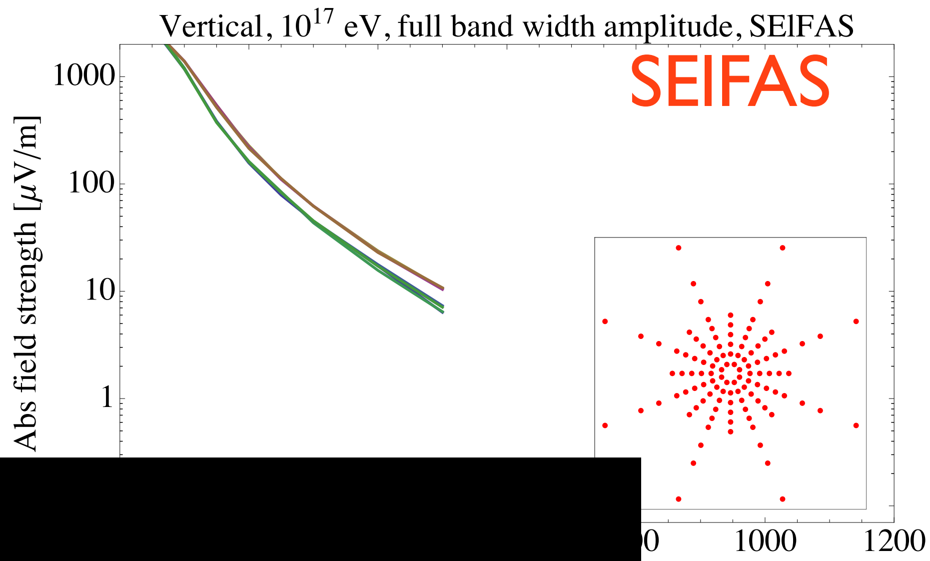


Auger B=0.23 Gauss θ=58°

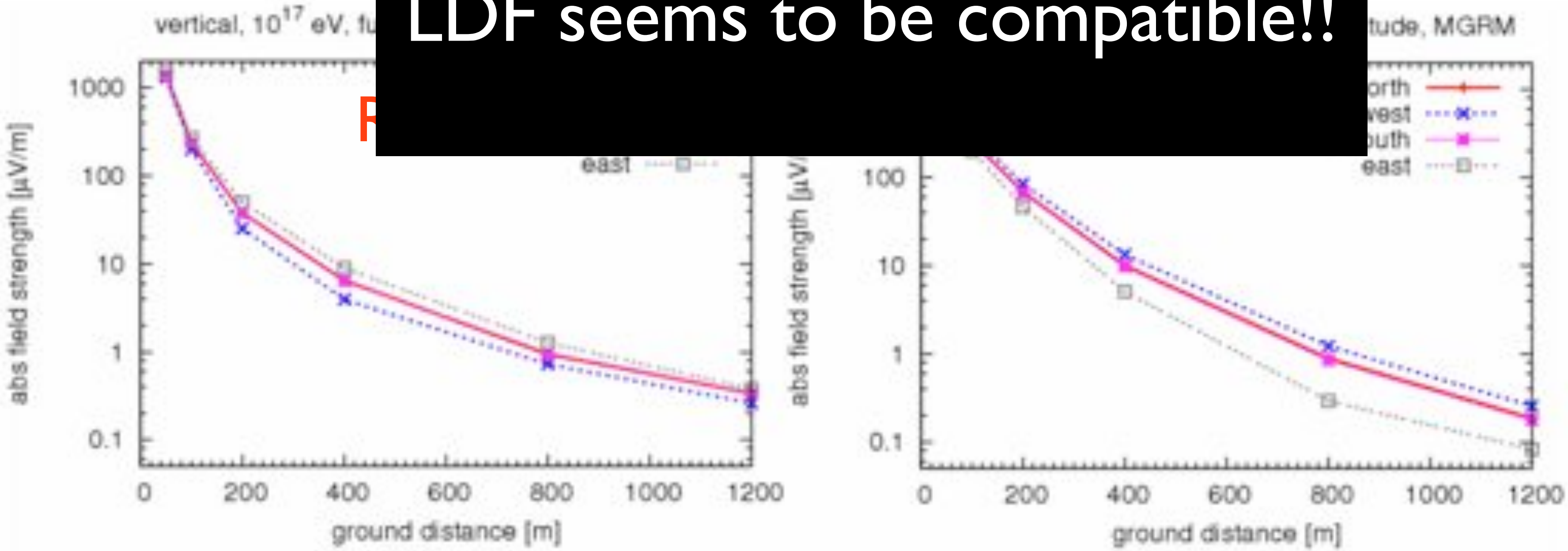
Conclusion

Nancay
magnetic field
B=0.50 Gauss
θ=27°

→



LDF seems to be compatible!!



Auger B=0.23 Gauss θ=58°

Conclusion

Lateral distribution function is φ-dependent

SEIFAS verify coherent-incoherent behavior

Extract a theoretical law between primary energy and measured signal

<u>Other work in progress</u>

Establish a more realistic model with:

«Vector-potential point of view»

Cerenkov radiation (Cf A. Romero-Wolf talk)

(bipolarity of the pulse)

Scattering effect

Effect of asymmetry between electrons and positrons

All these improvements are easily implementable in SEIFAS


Thanks...
Pierre Auger Observatory - Malargue Campus