*VHF - VERY HIGH FREQUENCY
*RREA - RELATIVISTIC RUNAWAY ELECTRON AVALANCHE

SIMULATION OF VHF SIGNAL FROM RREA

Khamitov Timur , MIPT

GOAL
Aragats antennas

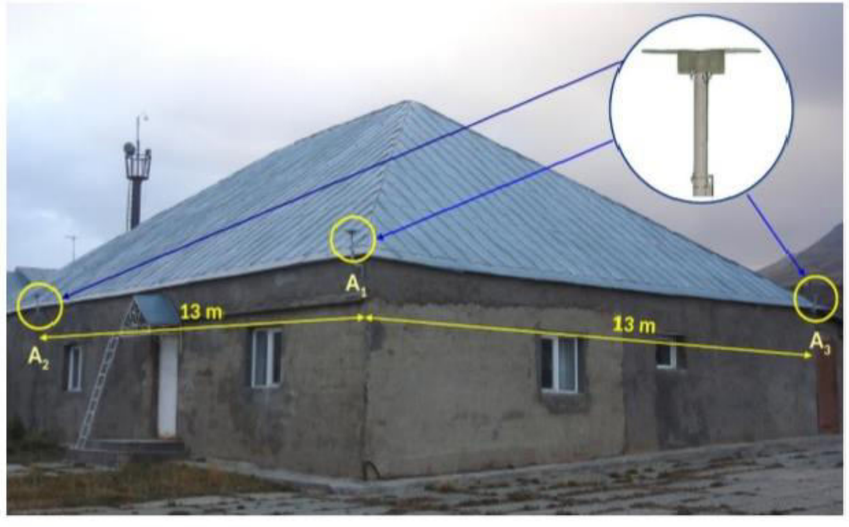
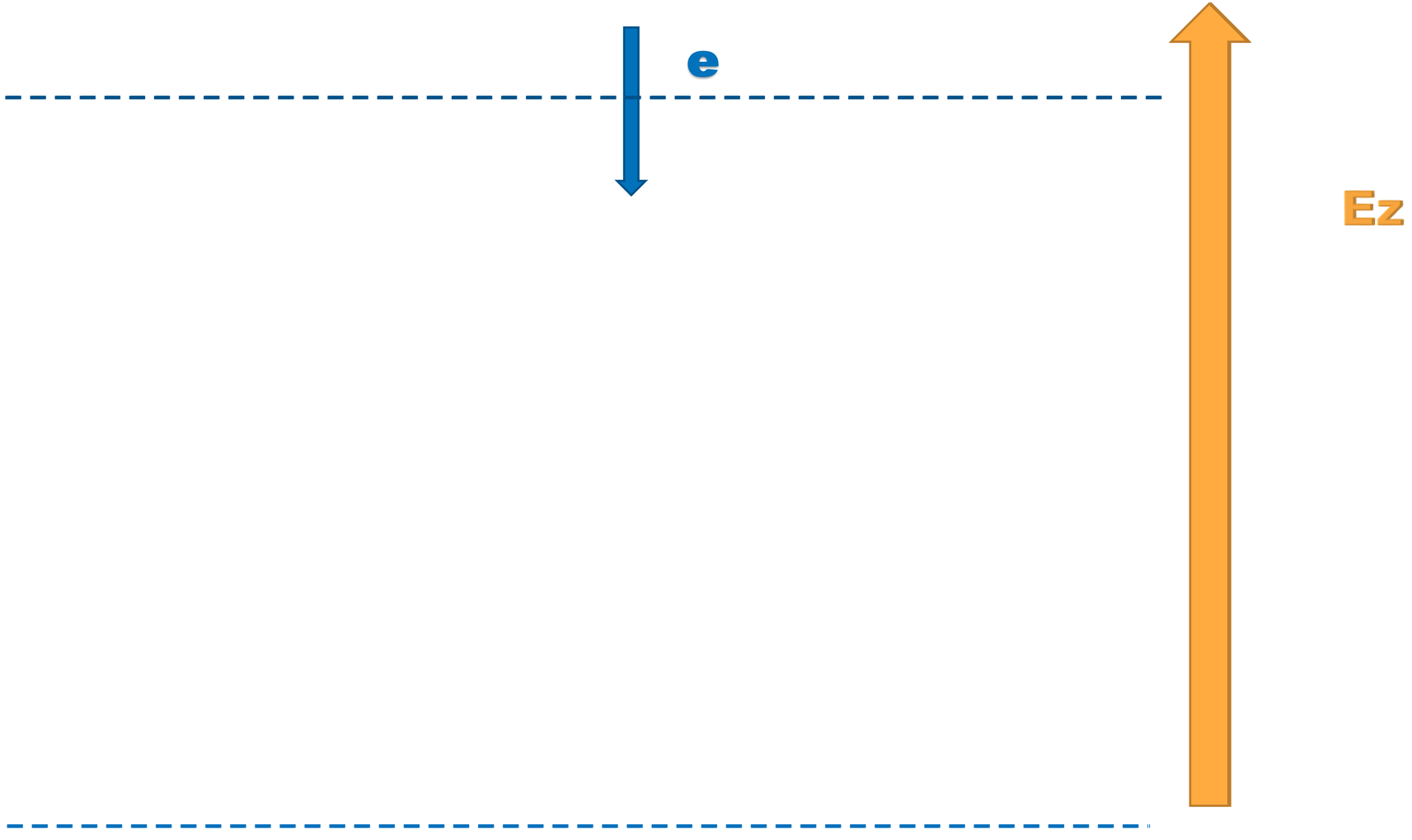


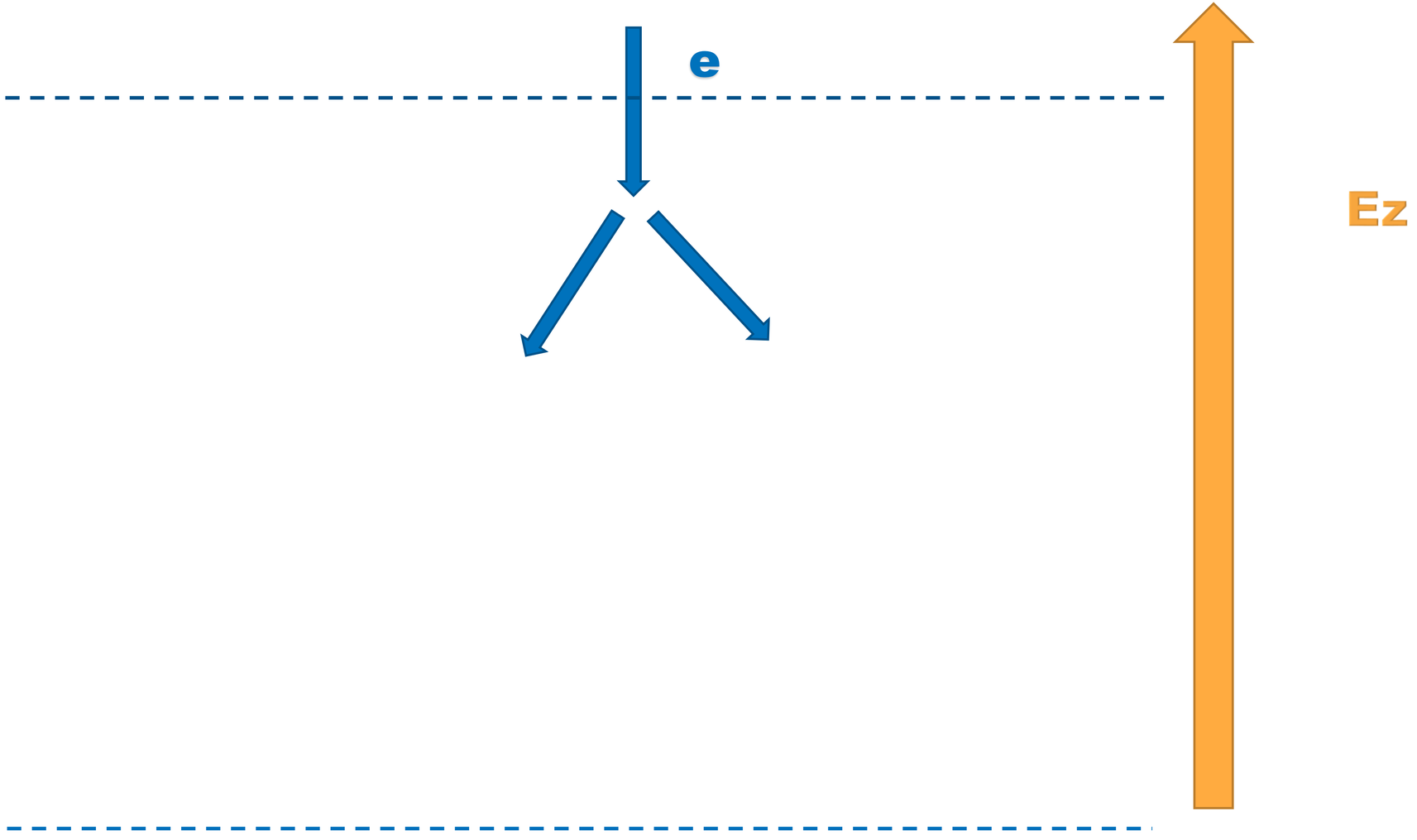
Image credits to CRD, YerPhI.

A. Kiselyov, M. Dolgonosov, S. Soghomonyan,V.Karedin

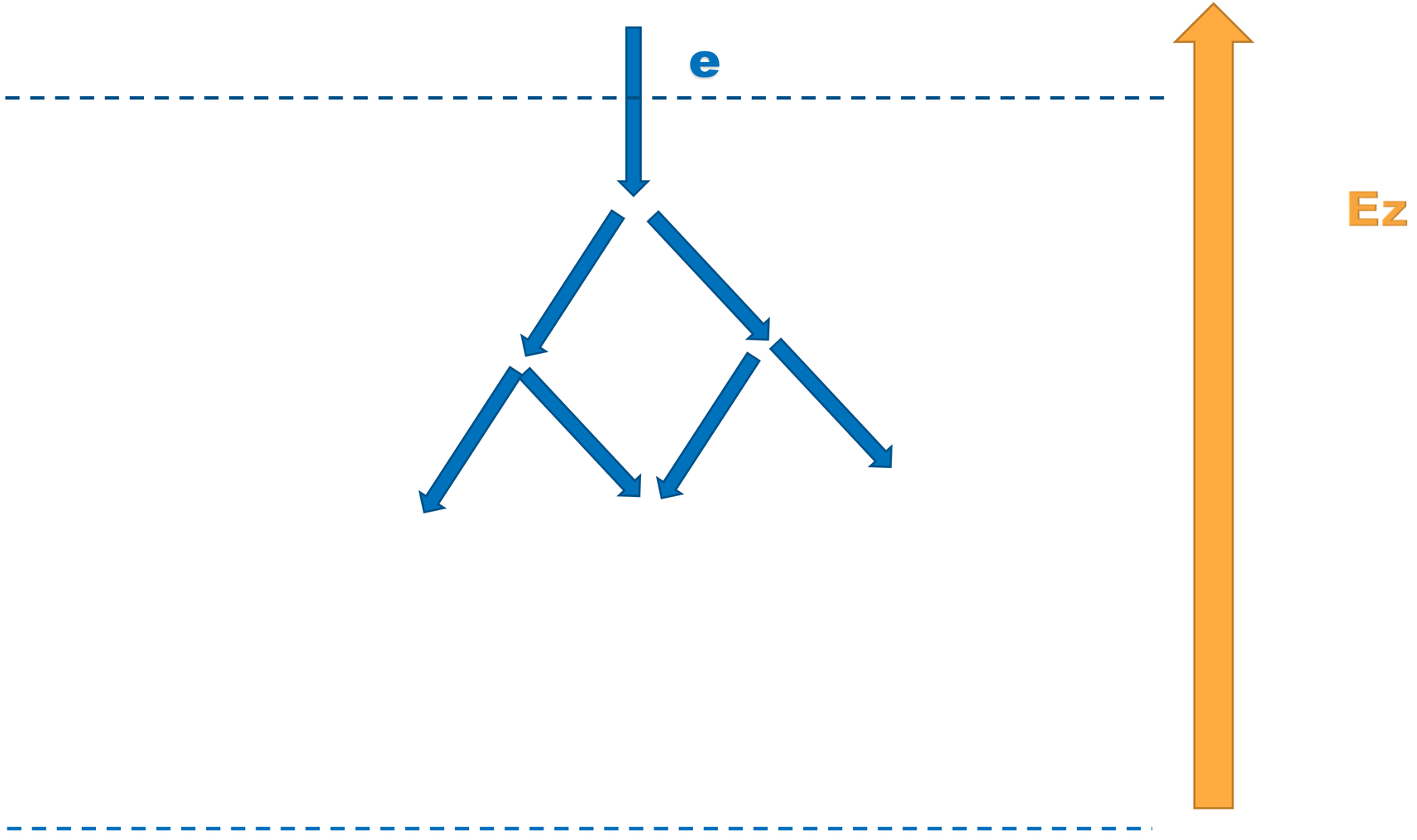
RELATIVISTIC RUNAWAY ELECTRON AVALANCHE



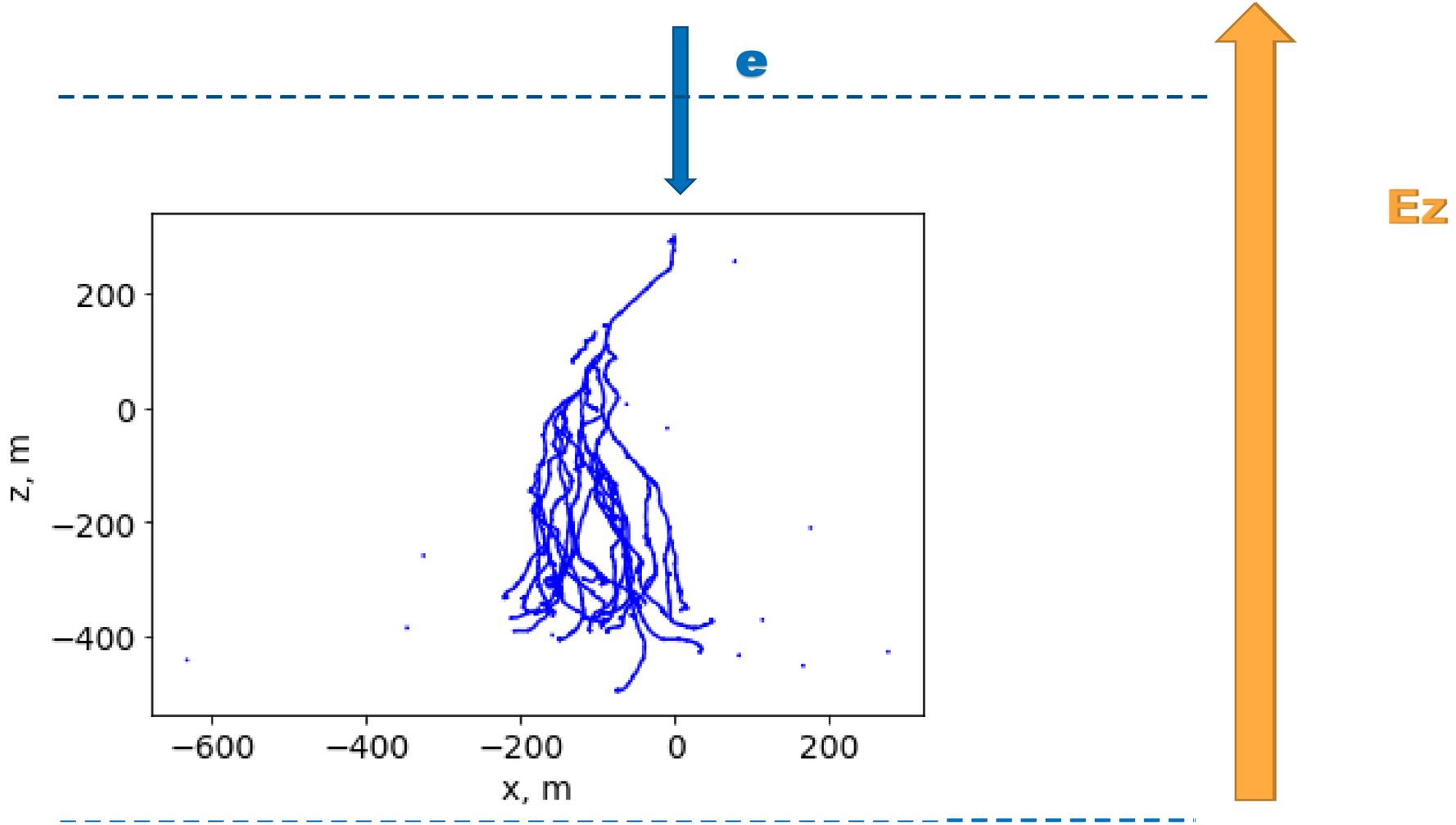
RELATIVISTIC RUNAWAY ELECTRON AVALANCHE



RELATIVISTIC RUNAWAY ELECTRON AVALANCHE

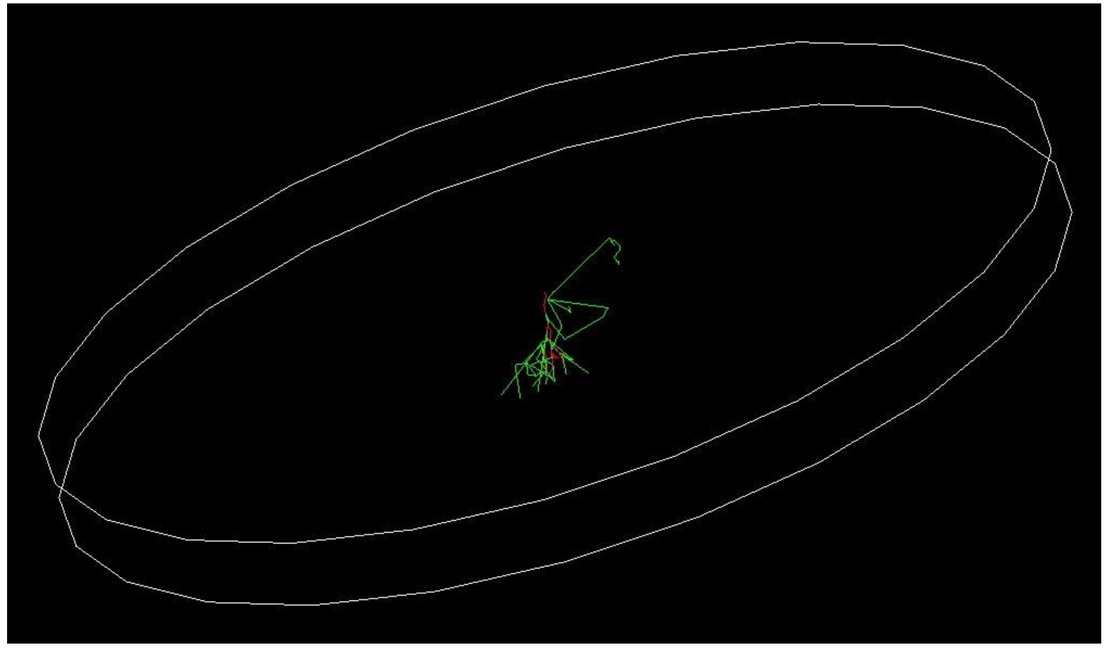


RELATIVISTIC RUNAWAY ELECTRON AVALANCHE



SIMULATION STEP BY STEP

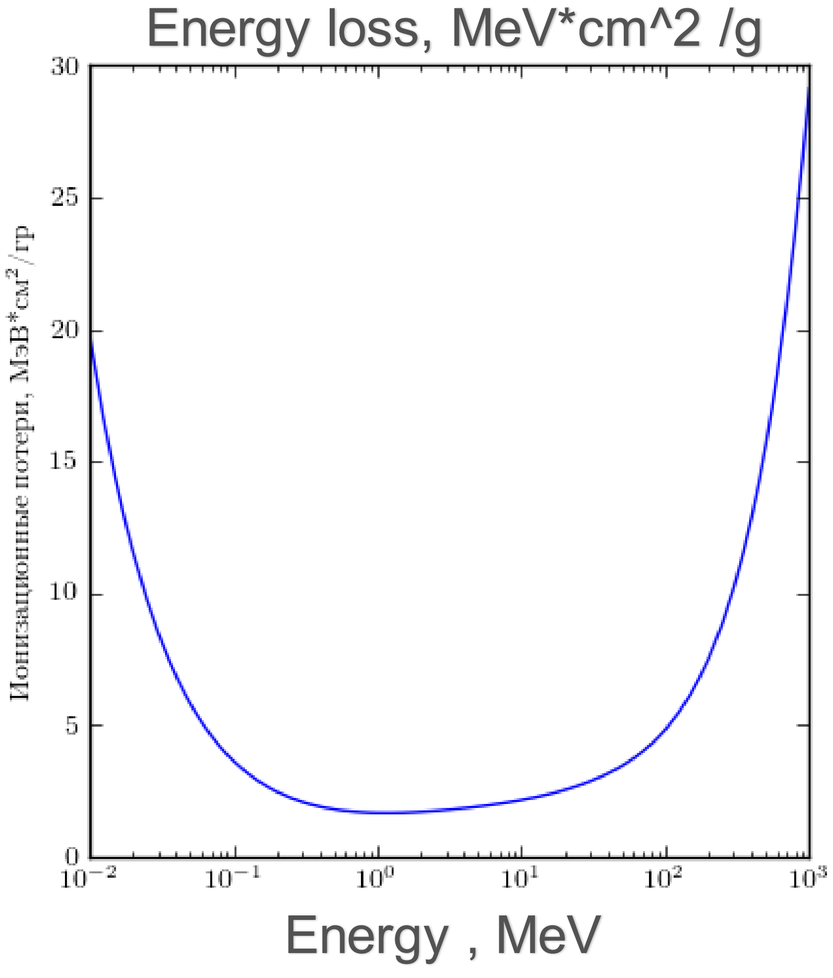
- Cylinder cell 600m height
- Placed at 10 km height
- 30 keV energy cut
- Cylinder is very wide (10 km)
- Seed electron 3 MeV
- Electric field 110 kV/m

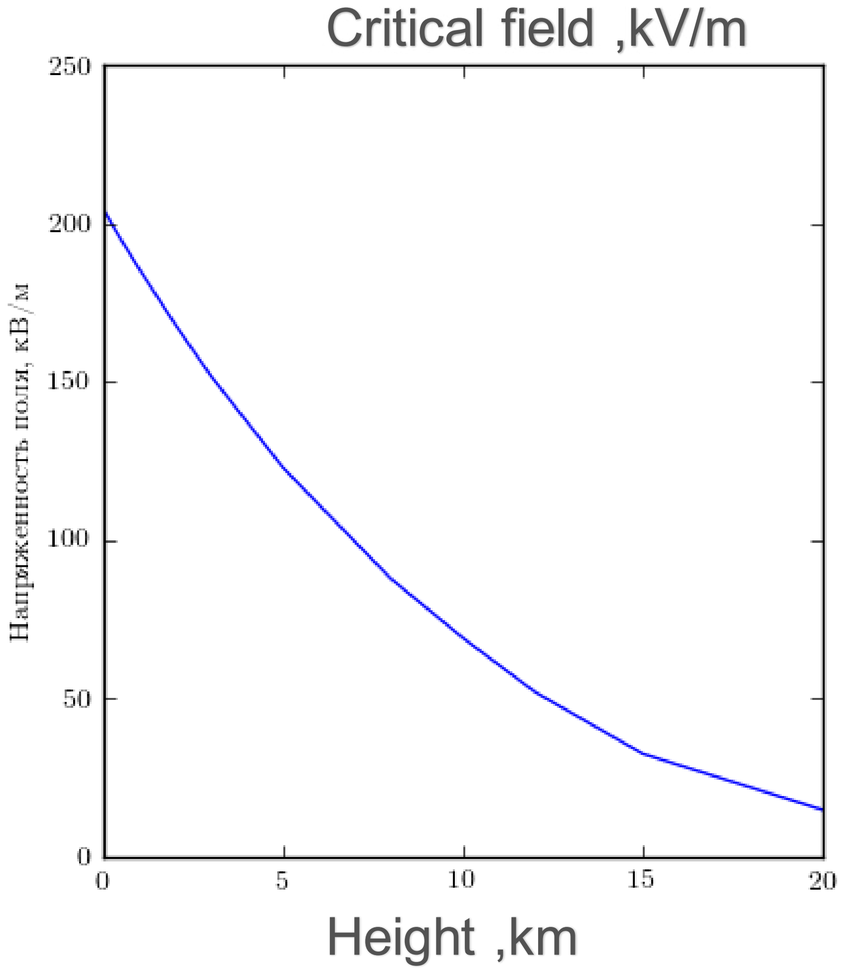


- A small green line is RREA 600 m height

SIMULATION STEP BY STEP

Gurevich (1992)





SIMULATION STEP BY STEP

- Cylinder cell 600m height
- Placed at 10 km height
- Electric field 110 kV/m
- 0.03 MeV energy cut
- Cylinder is very wide (10 km)

→ COORDINATES TIME → VELOCITY ACCELERATION →

SIMULATION STEP BY STEP

$$\mathbf{E}(\mathbf{r},t) = \frac{1}{4\pi\varepsilon_0}\left(\frac{q(\mathbf{n}-\boldsymbol{\beta})}{\gamma^2(1-\mathbf{n}\cdot\boldsymbol{\beta})^3|\mathbf{r}-\mathbf{r}_s|^2} + \frac{q\mathbf{n}\times\left((\mathbf{n}-\boldsymbol{\beta})\times\dot{\boldsymbol{\beta}}\right)}{c(1-\mathbf{n}\cdot\boldsymbol{\beta})^3|\mathbf{r}-\mathbf{r}_s|}\right)_{t_r}$$

$$\mathbf{B}(\mathbf{r},t) = \frac{\mu_0}{4\pi}\left(\frac{qc(\boldsymbol{\beta}\times\mathbf{n})}{\gamma^2(1-\mathbf{n}\cdot\boldsymbol{\beta})^3|\mathbf{r}-\mathbf{r}_s|^2} + \frac{q\mathbf{n}\times\left(\mathbf{n}\times\left((\mathbf{n}-\boldsymbol{\beta})\times\dot{\boldsymbol{\beta}}\right)\right)}{(1-\mathbf{n}\cdot\boldsymbol{\beta})^3|\mathbf{r}-\mathbf{r}_s|}\right)_{t_r} = \frac{\mathbf{n}(t_r)}{c}\times\mathbf{E}(\mathbf{r},t)$$

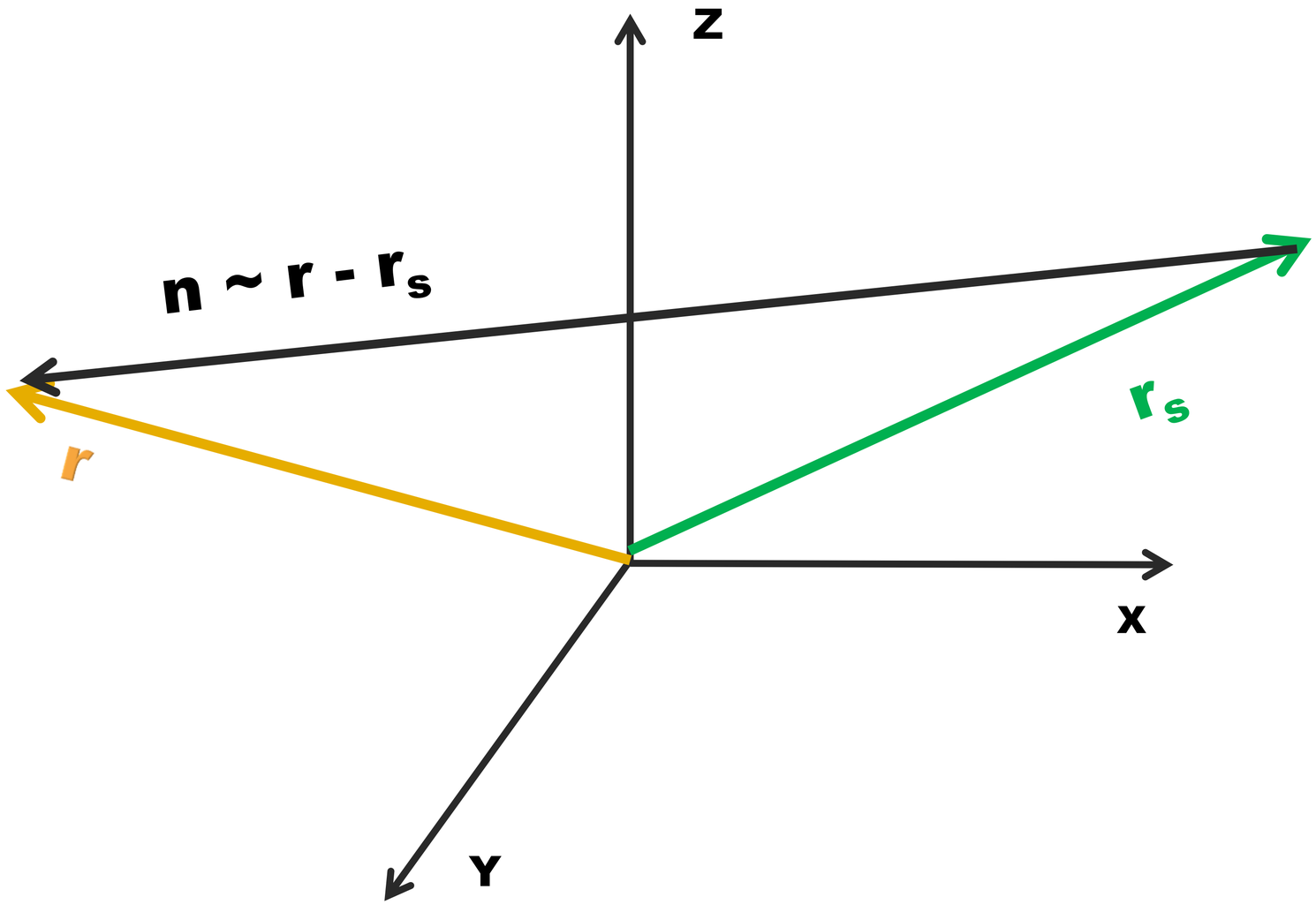
$$\gamma(t) = \frac{1}{\sqrt{1-|\boldsymbol{\beta}(t)|^2}} \qquad \boldsymbol{\beta}(t) = \frac{\mathbf{v}_s(t)}{c}$$

https://en.wikipedia.org/wiki/Li%C3%A9nard%E2%80%93Wiechert_potential

ELECTRIC AND MAGNETIC FIELDS FOR EACH PARTICLE AT EACH SIMULATION STEP

SIMULATION STEP BY STEP

$$\mathbf{n}(t) = \frac{\mathbf{r} - \mathbf{r}_s(t)}{|\mathbf{r} - \mathbf{r}_s(t)|}$$

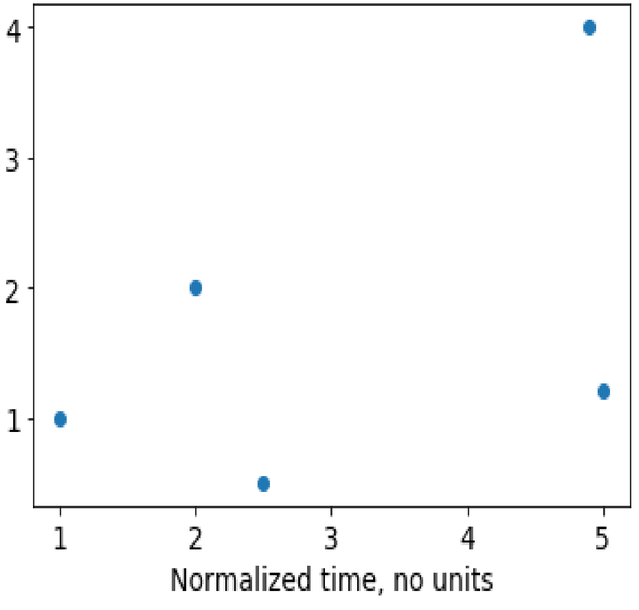


ELECTRIC AND MAGNETIC FIELDS FOR EACH PARTICLE AT EACH SIMULATION STEP

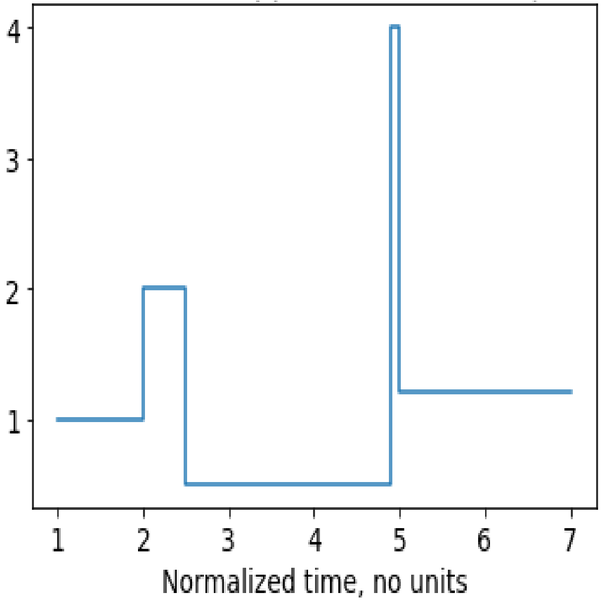
SIMULATION STEP BY STEP

$$Ei = \sum_{t}^{Mi} Et$$

Track field after geant4



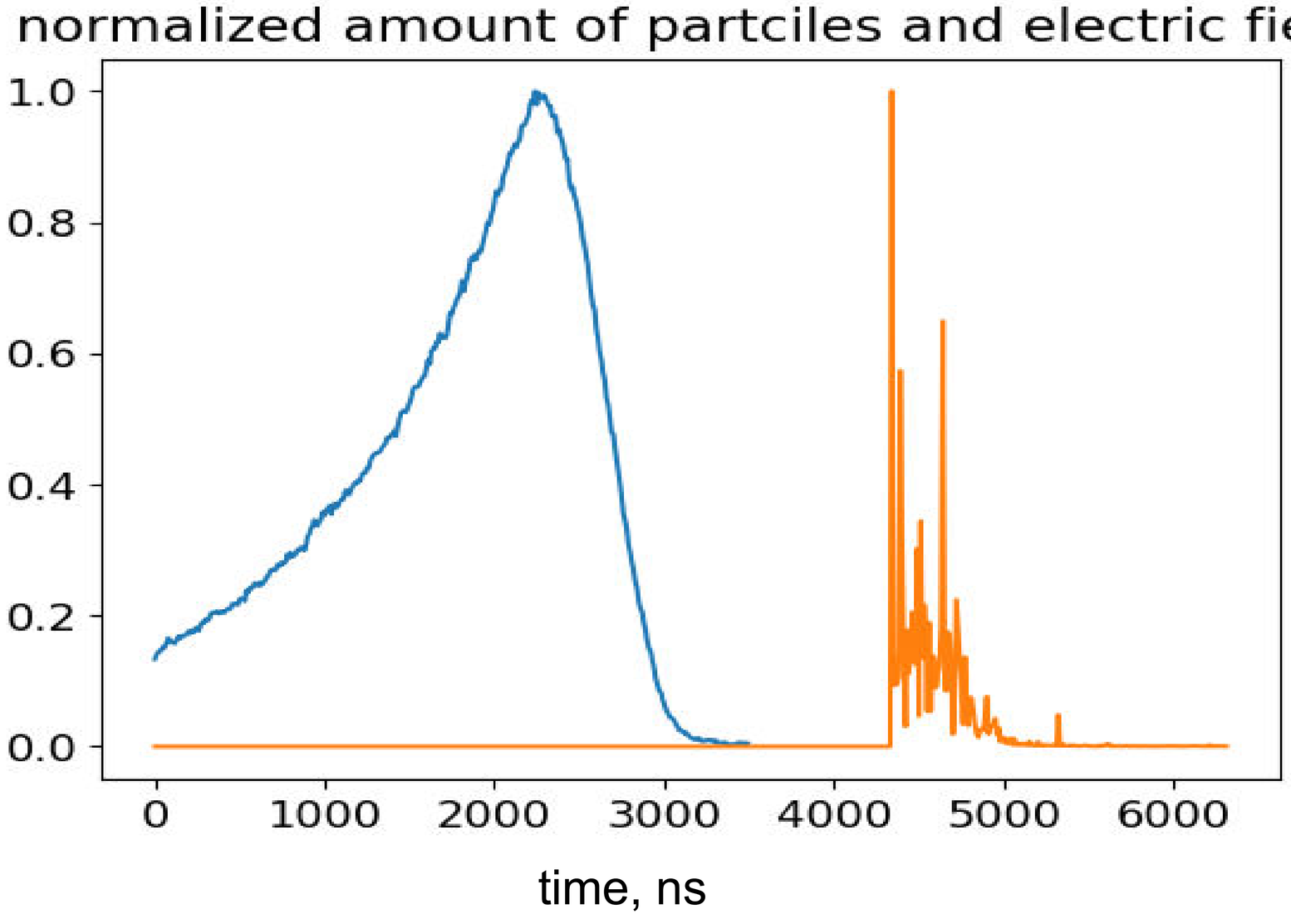
Approximated track field



$$E = \frac{\sum_{i}^{N} Ei}{N}$$

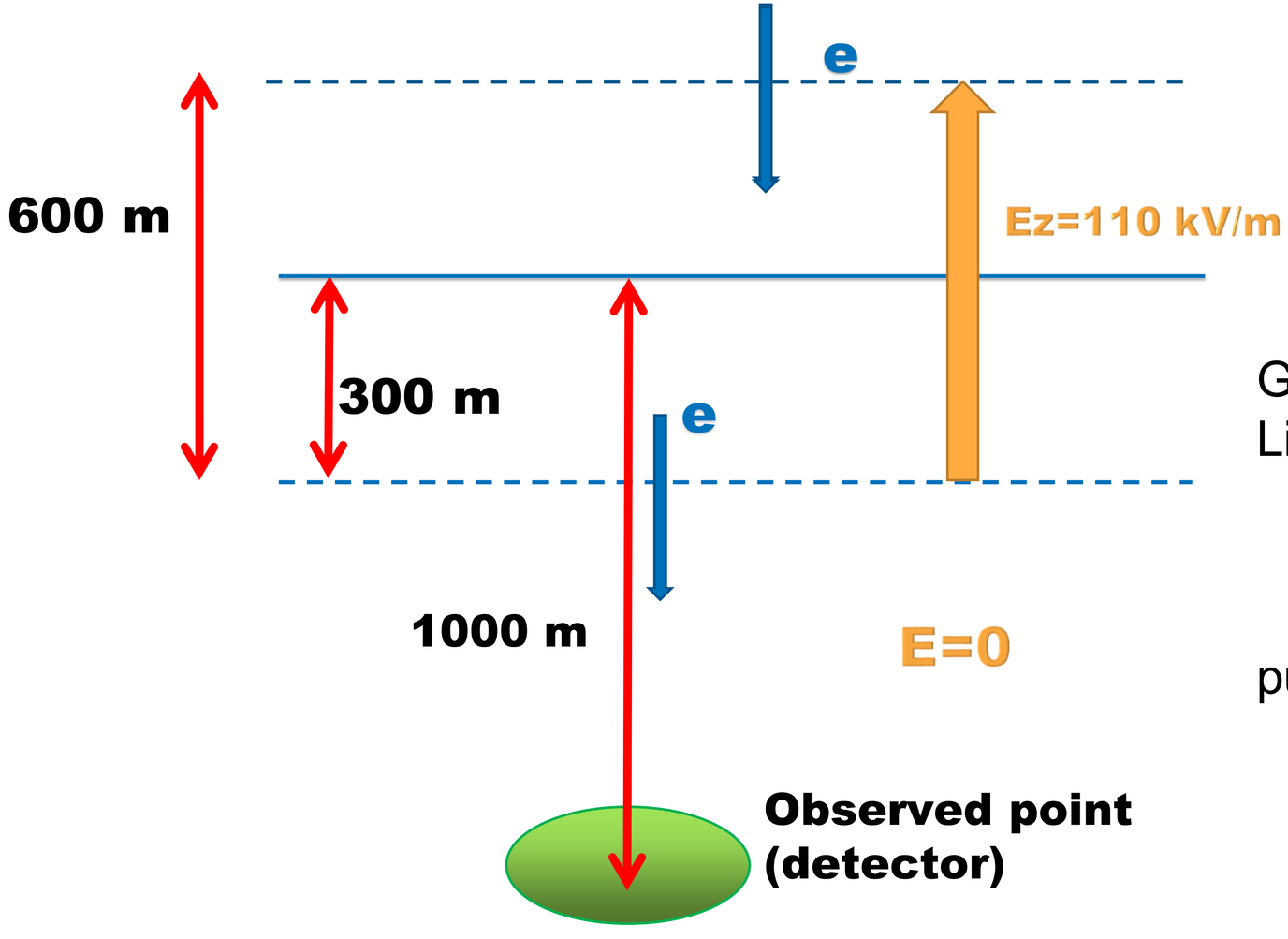
i - simulation number
Ei - field in i-simulation
N - simulations amount
Et - track field
t - track number
Mi - simulation tracks amount

DELAY AND COMPRESSION



- **Amount of particles**
- **Electric field pulse**

DELAY AND COMPRESSION

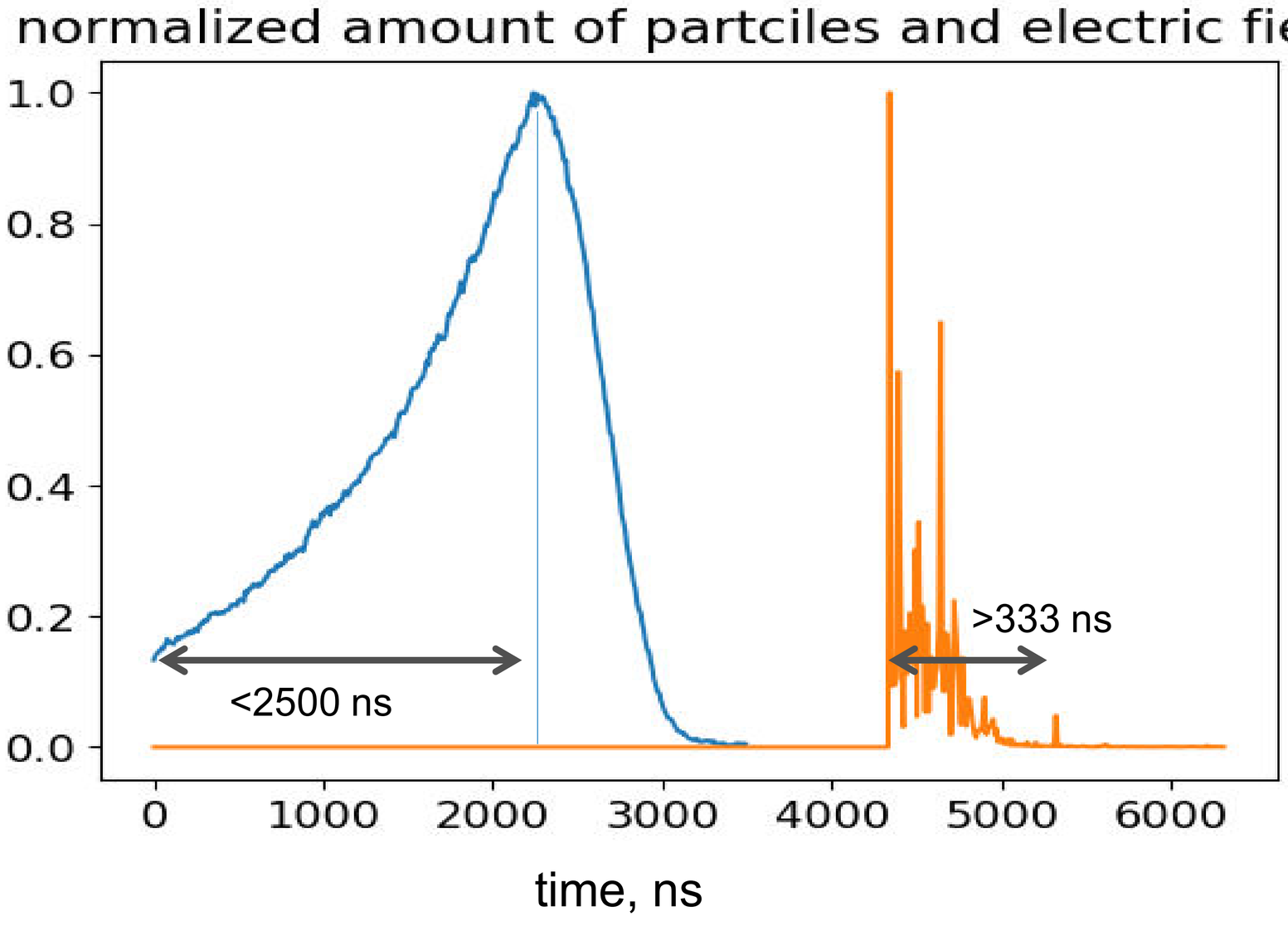


H = 600m - cell size
V = 0.8*C - electrons velocity for estimation
h = 1000m - distance to observed point

Growth time = H/V = 2500 ns
Light arrival times:
for seed electron = (H/2+h)/C ~ 4300 ns
for the last one =H/0.8C + (h-H/2)/C ~ 4633 ns

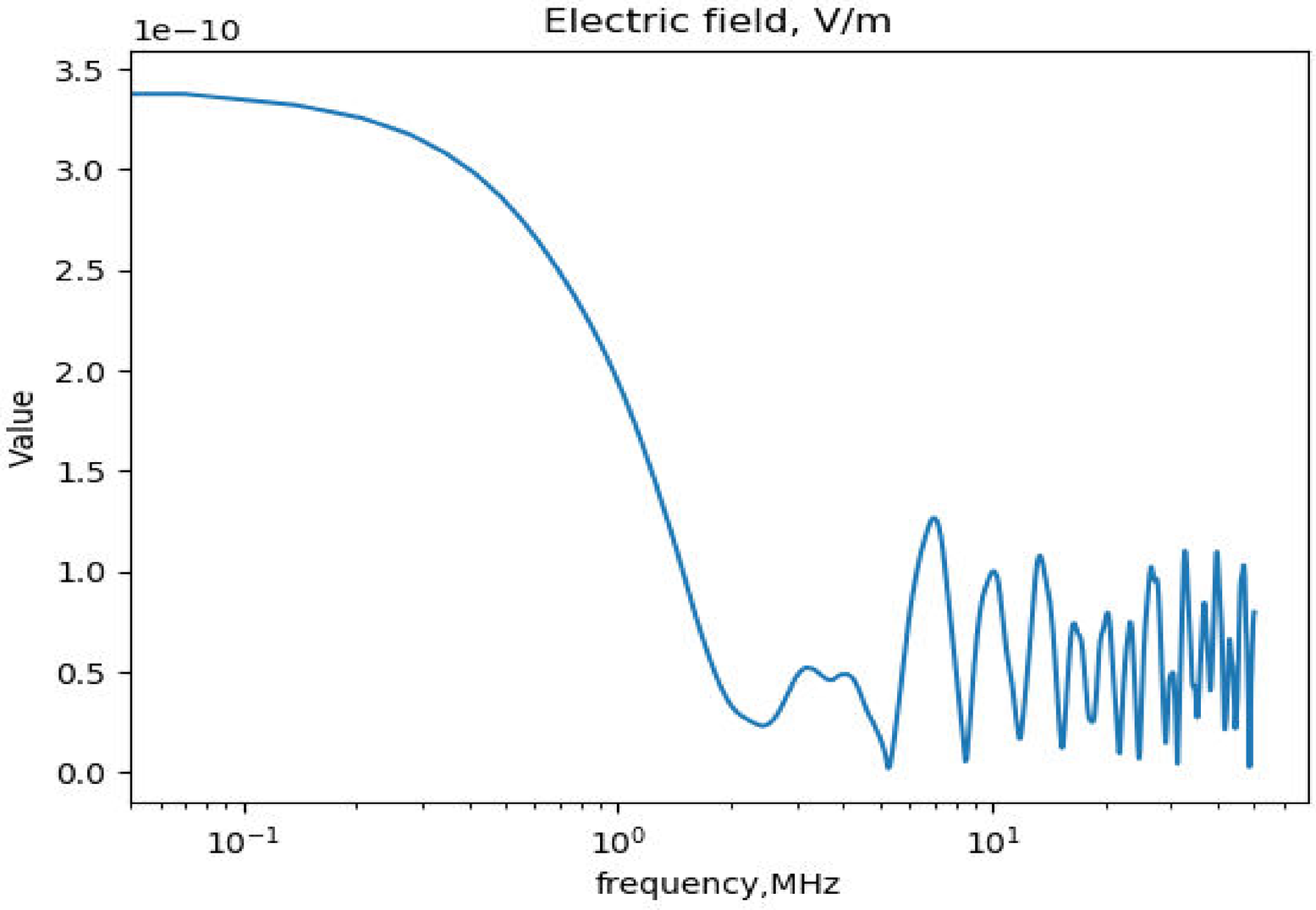
pulse duration > 4633 - 4300 = 333 ns

DELAY AND COMPRESSION

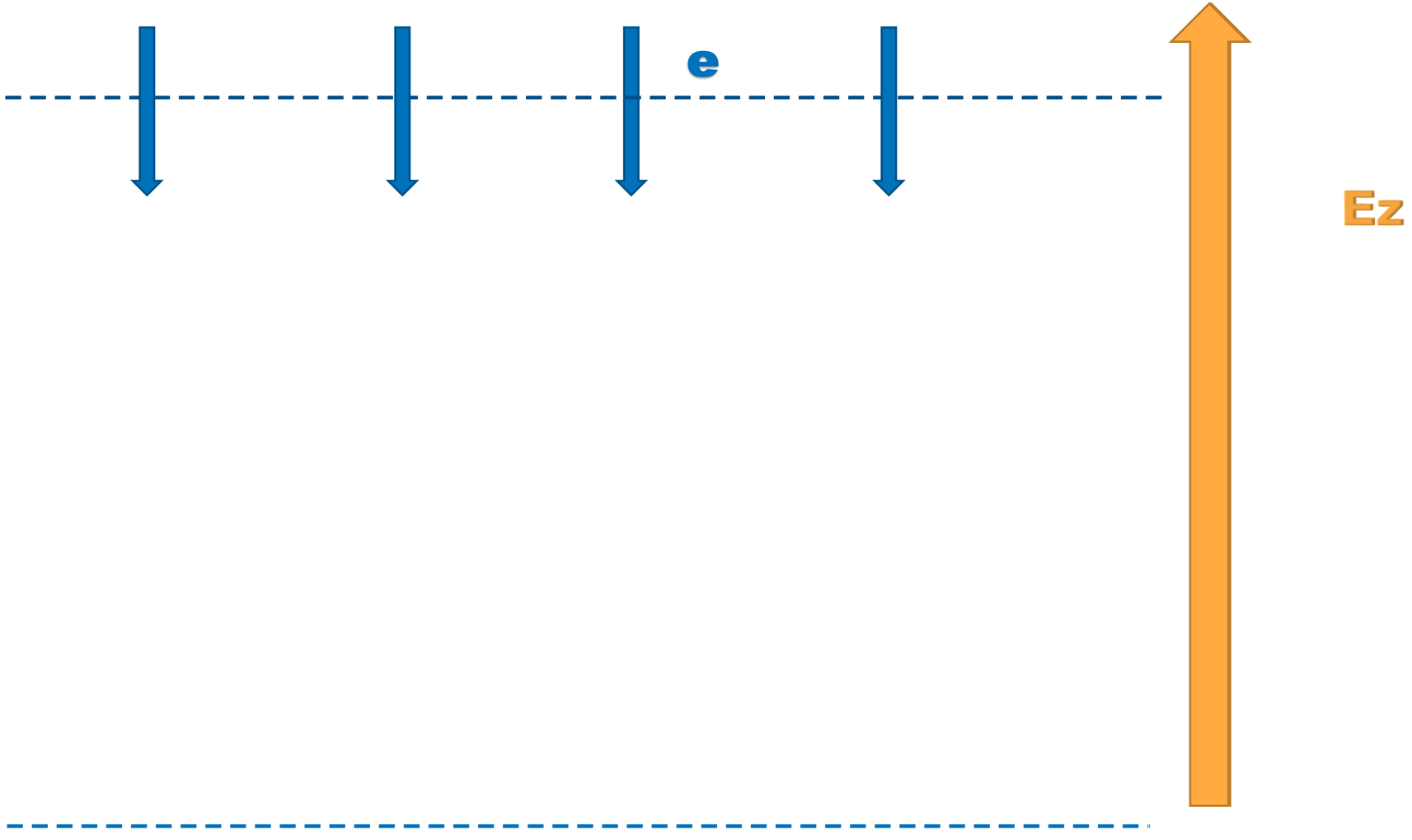


- **Amount of particles**
- **Electric field pulse**

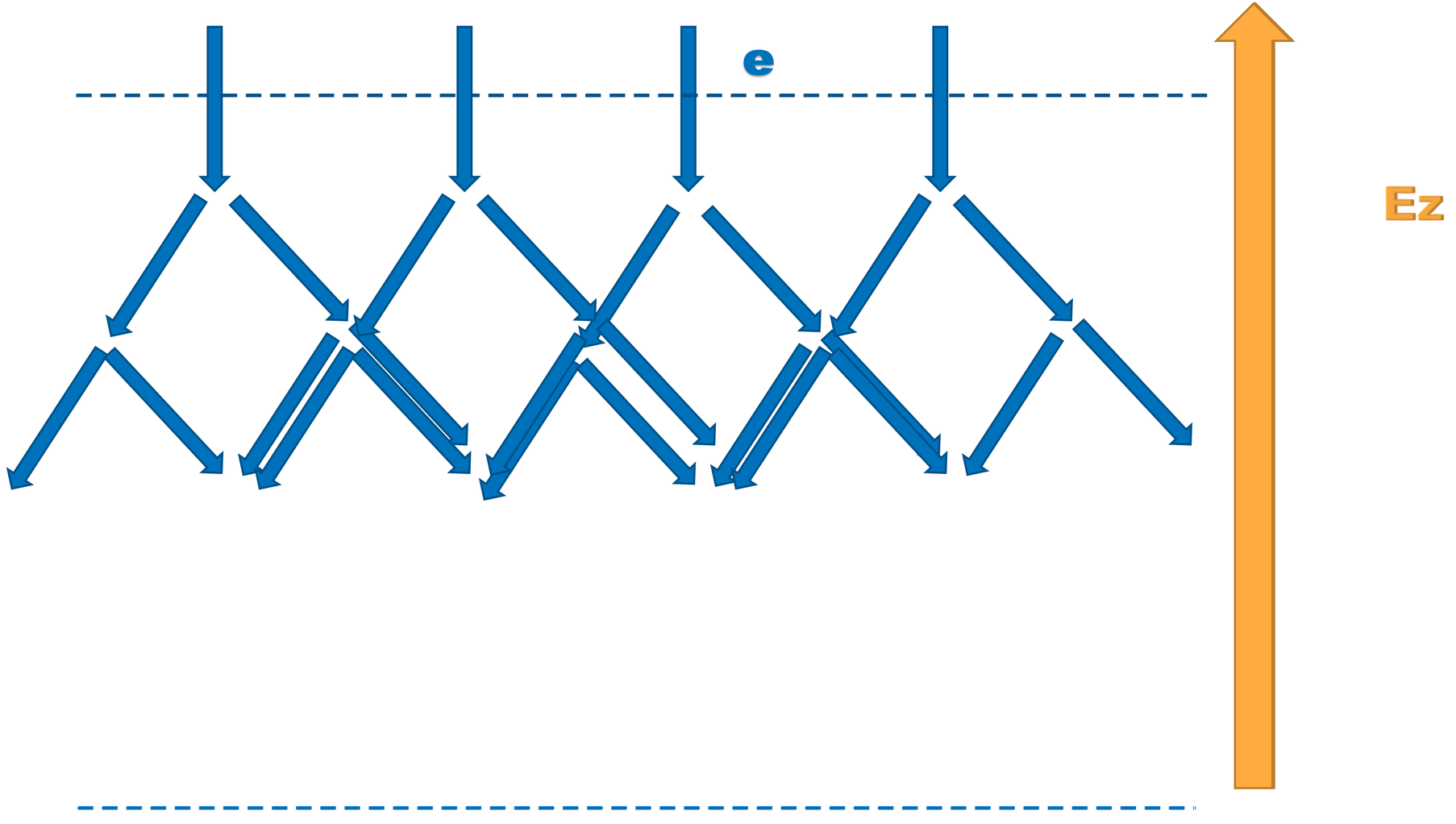
SPECTRUM


Electric field, V/m
1e−10
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Value
10^{-1}
10^{0}
10^{1}
frequency,MHz

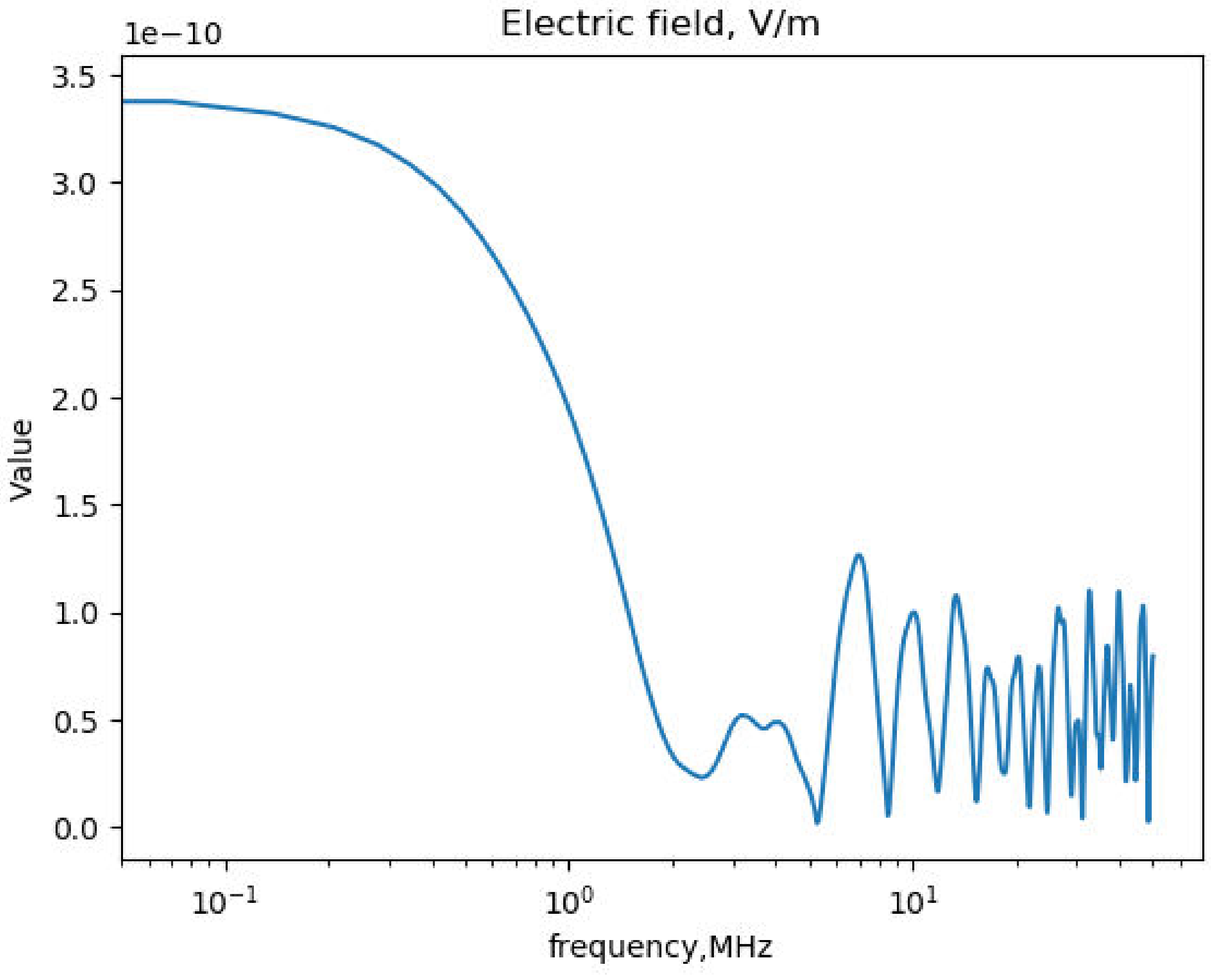
RELATIVISTIC RUNAWAY ELECTRON AVALANCHE



RELATIVISTIC RUNAWAY ELECTRON AVALANCHE



SPECTRUM,MEASURABILTY



Peak value 3*10^(-10) V/m is unmeasurable

Seed flux density is 1000 electrons per second per square meter *

Coherence time ~ 1000 ns ->

->seed flux 1000 electrons per square km per microsecond

Multiplyed value ~ 3*10^(-7) V/m

* Astrophysics and Space Science Library 303) Lev I. Dorman (auth.)-Cosmic Rays in the Earth's Atmosphere and Underground-Springer Netherlands (2004)

MEASURABILTY: alternative estimation

$$E_z(r,t) = \frac{1}{2\pi\epsilon_0}\int_{h_1}^{h_2}\left[dz\frac{(2z^2-r^2)}{R^5(z)}\int_{t_b(z)}^{t} i\left(z,\tau-\frac{R(z)}{c}\right)d\tau + \frac{(2z^2-r^2)}{cR^4(z)}i\left(z,t-\frac{R(z)}{c}\right)dz - \frac{r^2}{c^2R^3(z)}\frac{di\left(z,t-\frac{R(z)}{c}\right)}{dt}dz\right],$$

R - distanse to observed point

r - horizontal projection of R

h1,h2 - cell top and bottom heights

I - current , delta ~ 1 or 2 m

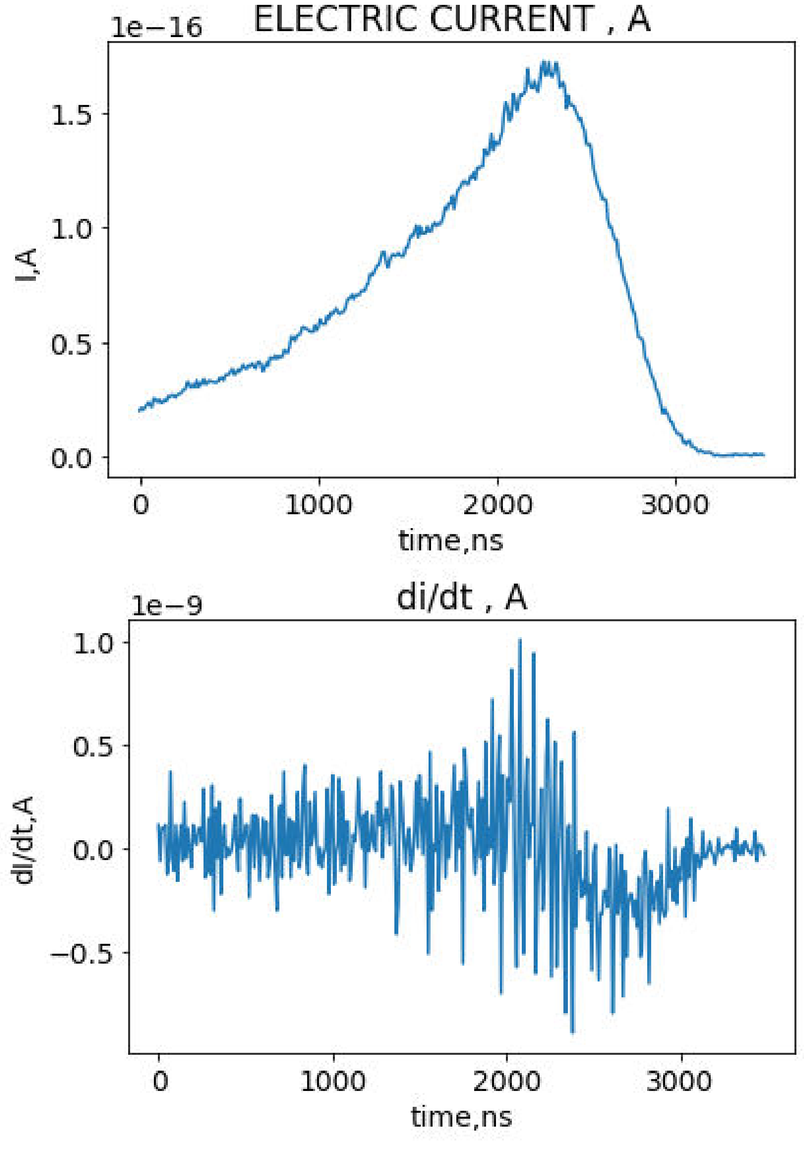
I=e*N*V/(delta)

N - amount of particles in RREA

Amitabh Nag and Vladimir A. Rakov, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D20102,doi:10.1029/2010JD014235, 2010

MEASURABILTY: alternative estimation

$$E_z(r,t) = \frac{1}{2\pi\epsilon_0}\int_{h_1}^{h_2}\left[dz\,\frac{(2z^2-r^2)}{R^5(z)}\int_{t_b(z)}^{t} i\left(z,\tau-\frac{R(z)}{c}\right)d\tau + \frac{(2z^2-r^2)}{cR^4(z)}i\left(z,t-\frac{R(z)}{c}\right)dz - \frac{r^2}{c^2R^3(z)}\frac{di\left(z,t-\frac{R(z)}{c}\right)}{dt}dz\right],$$



Amitabh Nag and Vladimir A. Rakov, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D20102,doi:10.1029/2010JD014235, 2010

MEASURABILTY: alternative estimation

$$E_z(r,t) = \frac{1}{2\pi\epsilon_0}\int_{h_1}^{h_2}\left[dz\frac{(2z^2-r^2)}{R^5(z)}\int_{t_b(z)}^{t} i\left(z,\tau-\frac{R(z)}{c}\right)d\tau + \frac{(2z^2-r^2)}{cR^4(z)}i\left(z,t-\frac{R(z)}{c}\right)dz - \frac{r^2}{c^2R^3(z)}\frac{di\left(z,t-\frac{R(z)}{c}\right)}{dt}dz\right],$$

Amitabh Nag and Vladimir A. Rakov,
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D20102,doi:10.1029/2010JD014235, 2010

R - distanse to observed point

r - horizontal projection of R

h1,h2 - cell top and bottom heights

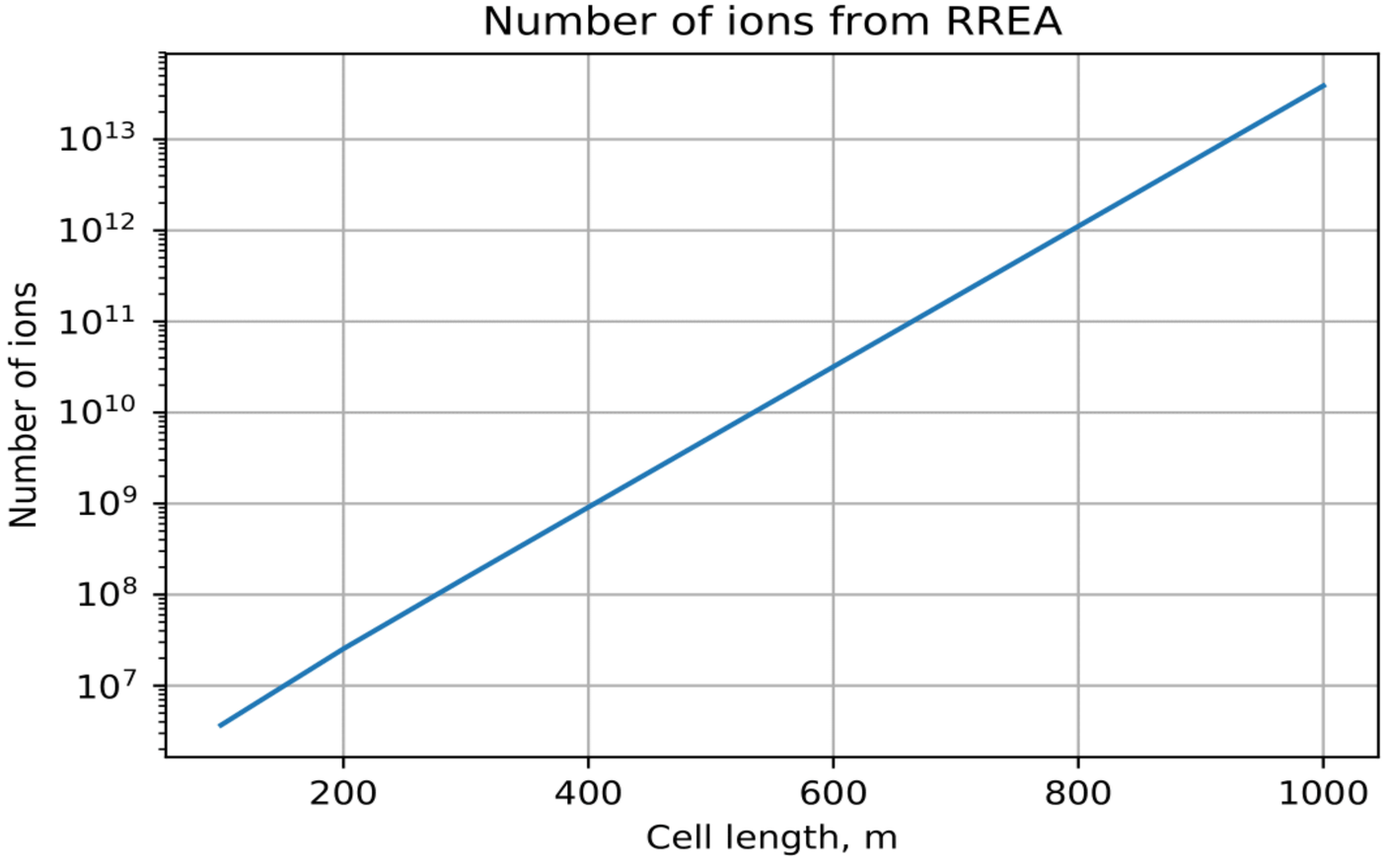
i - current

di/dt = e*dN/dt , N - amount of particles in RREA

r = 500m , R = 1000m ,
di/dt = 10^(-9) A/s
h1= 700m , h2 = 1300m

=> E~10^(-10) V/m

MEASURABILTY: low energy particles



10^7 - 10^9 times higher amount of particles

10^(6) times lower velocity

https://www.overleaf.com/project/5cc1ad9ca595920ee3c77c33

SUMMARY

High energy electrons can not produce measurable VHF signal

Low energy particles also unlikely to be the source of measurable radio waves

Observed pulses folowing RREA are something else

THANKS FOR YOUR ATTENTION!

CONTACTS:

KHAMITOV TIMUR MURATOVICH

mobile +7 (926) 451 67 13

E-mail timuruh@mail.ru

Address Dolgoprudny,Pervomayskaya street

MIPT at a glance

Rankings

#48
THE Physics

#67
THE Computer Science

#42
QS Physics & Astronomy

Alumni

Yuriy Baturin
Pilot astronaut, Hero of the Russian Federation

Alexander Kaleri
Pilot astronaut, Hero of the Russian Federation

Konstantin Novoselov
Nobel prizeman

Andrei Geim
Nobel prizeman

David Yan
Founder and Director of the board of ABBYY

Sergey Belousov
Founder and CEO of Acronis

Numbers

Founded in **1951**

Nobel prizemen among professors and alumni

80 Labs on campus

7132 Students

Phystech Schools

- Radio Engineering and Computer Technology
- Fundamental and Applied Physics
- Aerospace Technology
- Applied Mathematics and Informatics
- Biological and Medical Physics
- Electronics, Photonics and Molecular Physics