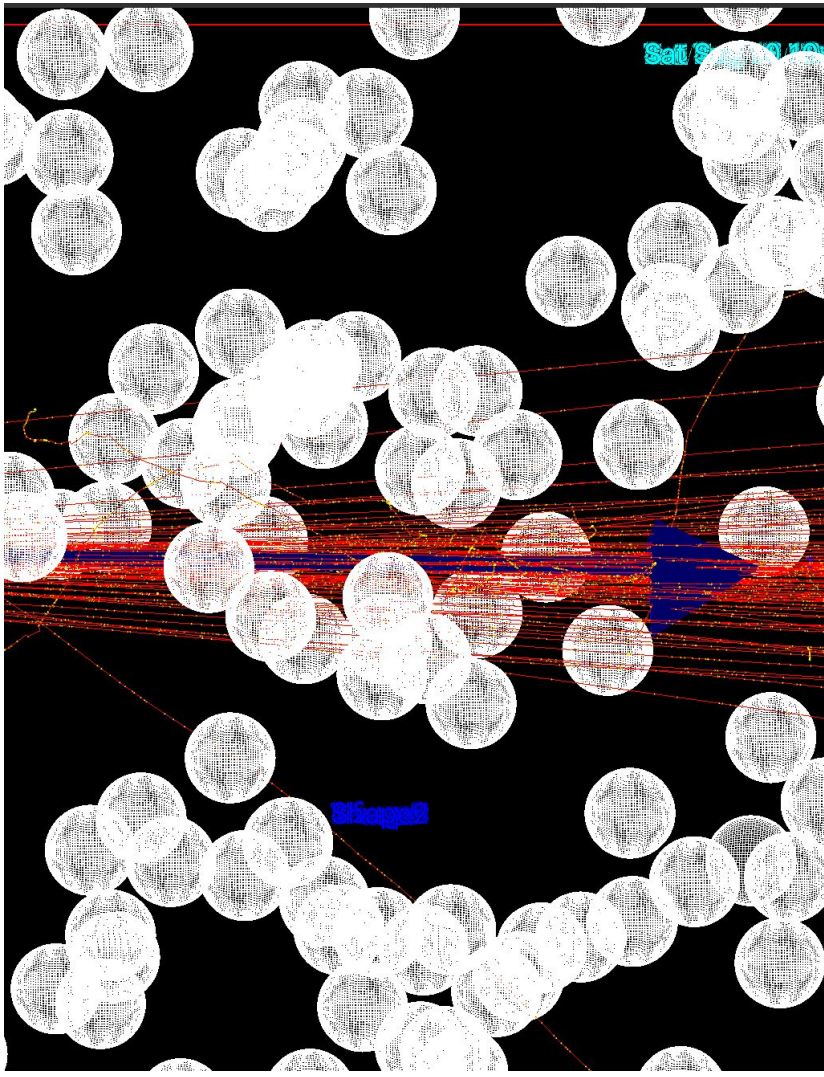
arXiv:2210.01916

Influence of hydrometeors on relativistic runaway electron avalanches

Daria Zemlianskaya
Egor Stadnichuk
Ekaterina Svechnikova

zemlianskay.d@phystech.edu



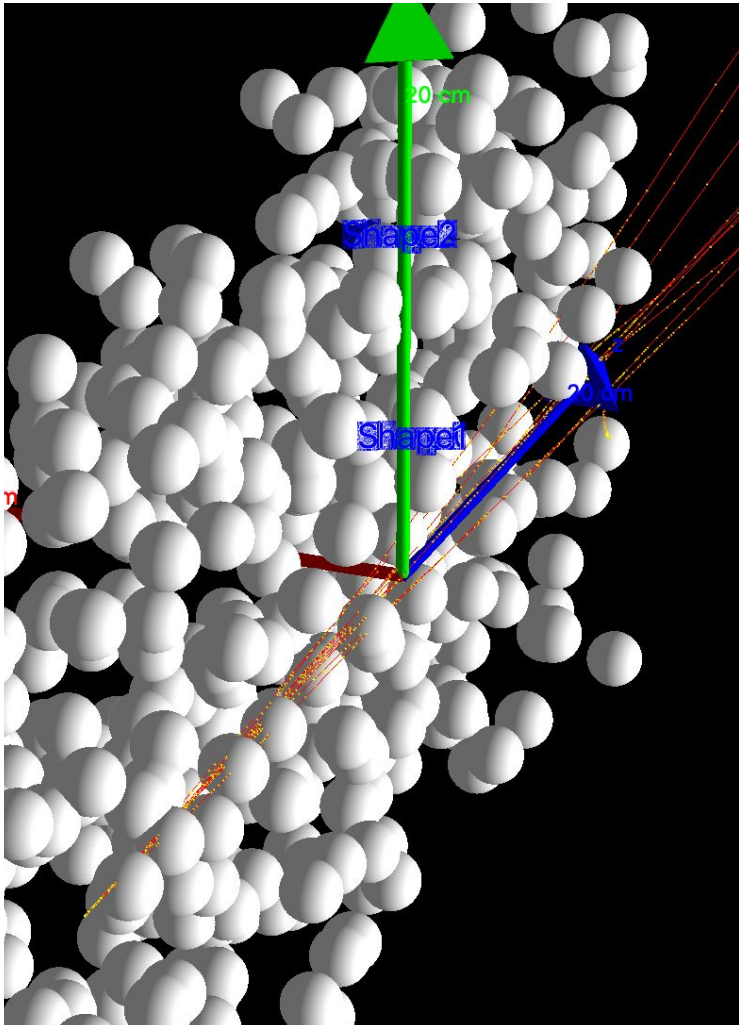
Motivation

- It is known for sure that hydrometeors in the cloud are responsible for the electric fields

- This is the first study on the propagation of relativistic avalanches of runaway electrons, taking into account the presence of hydrometeors in clouds

- Simulation in GEANT4 which consists of a cell of 200 meters (side) and a field of 200 kV/m, the electron beam is launched at the beginning of this cell

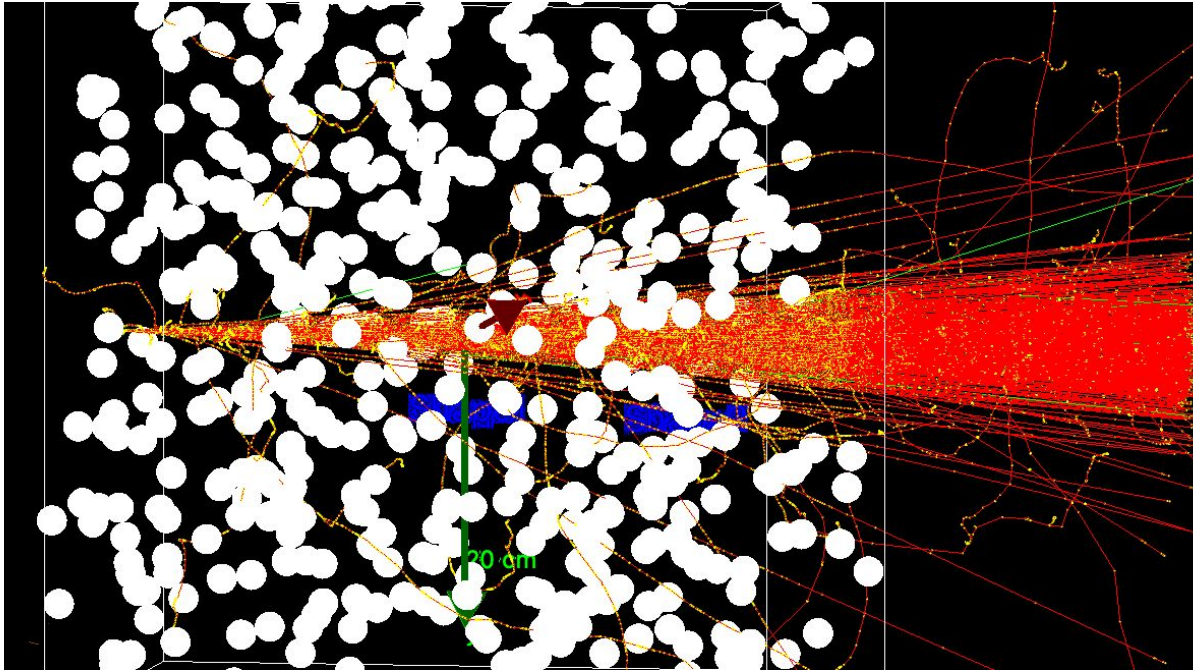
- The field accelerates this beam and creates an avalanche of relativistic runaway electrons



zemlianskay.d@phystech.edu

Volumetric hydrometeors

- Hydrometeors are stimulated like balls of ice with a density of 900 kg/m3
- Typical amount - 0.5 g/m3 (mass density) on average, upper limit - 5 g/m3 (1.25% in a 200 m cell)
- The distribution of snowflakes is random over the entire volume of the cell with a field

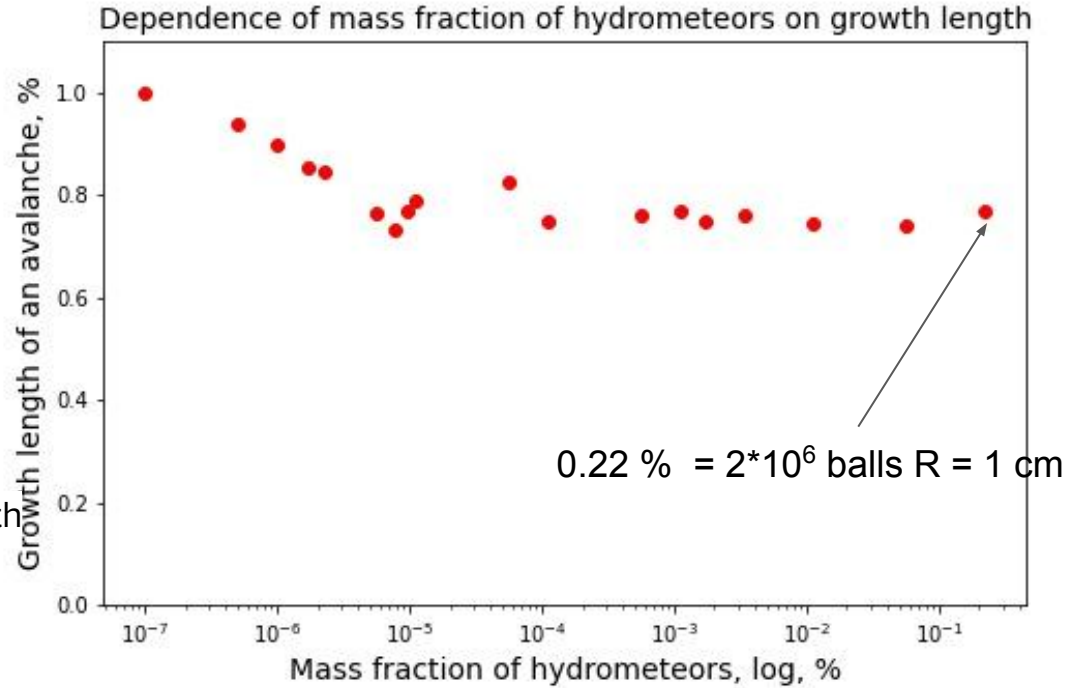


schematic picture

zemlianskay.d@phystech.edu

Hydrometeors, R = 1 cm

- 0 hydrometeors - growth length 91.89 m
- Minimum when adding hydrometeors - 67.45 m
- The growth length of an avalanche of relativistic runaway electrons decreases with a small number of hydrometeors and reaches a stable value

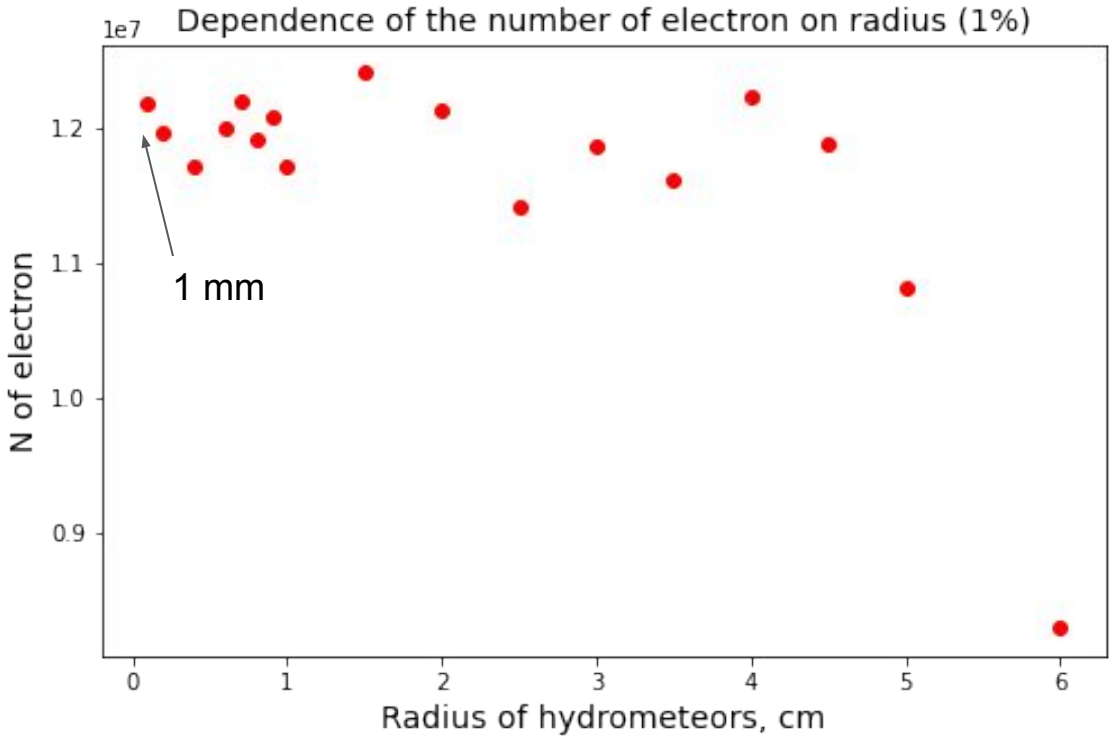


zemlianskay.d@phystech.edu

Radius of hydrometeors

cell: 50*50*50*cm^3

- Realistic hydrometeors are much smaller than in the simulation before
- We fixed 1 % by weight. From it and a different radius, the number of hydrometeors created was calculated
- It is observed that hydrometers up to 4 cm give approximately the same result and our approximation of 1 cm radius is valid

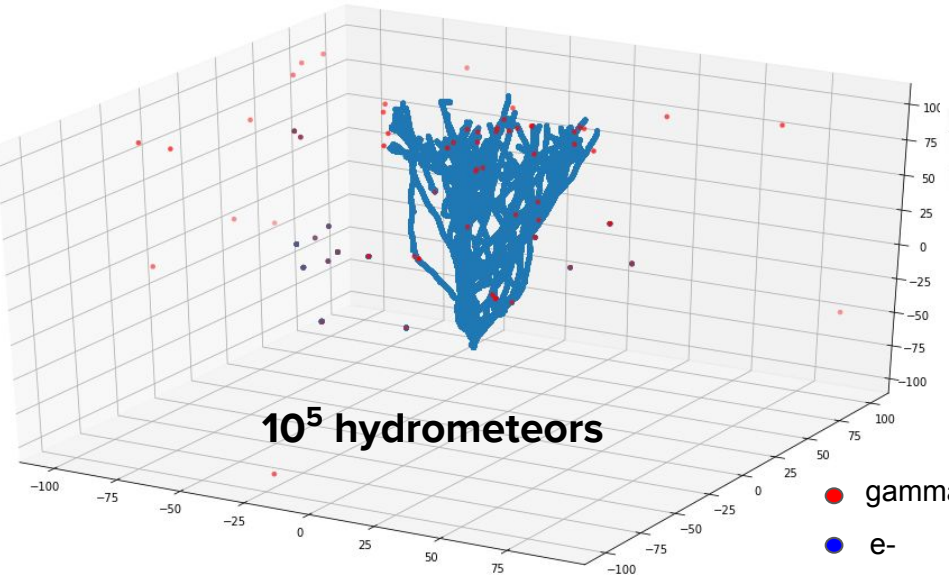


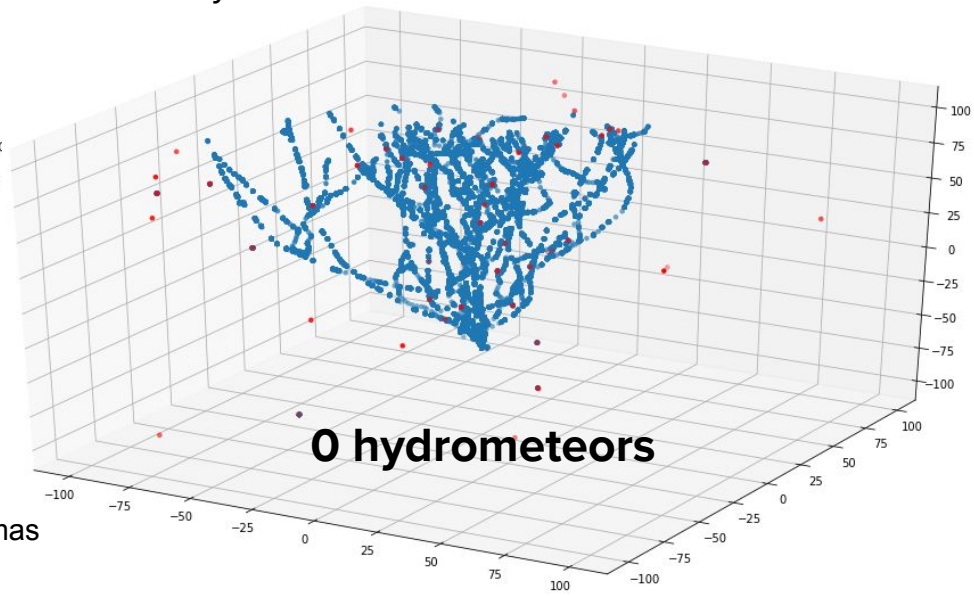
zemlianskay.d@phystech.edu

No Gamma Influence

It remains also to check whether the appearance of a gamma in the system can influence.

- gammas do not participate in this effect in any way (gammas are not affected by the electric field and (as we can see from the picture) it does not multiply due to hydrometeors)
- hydrometeor simulation narrows the beam
- gammas were also removed in the simulation with their secondary and this also did not affect the results



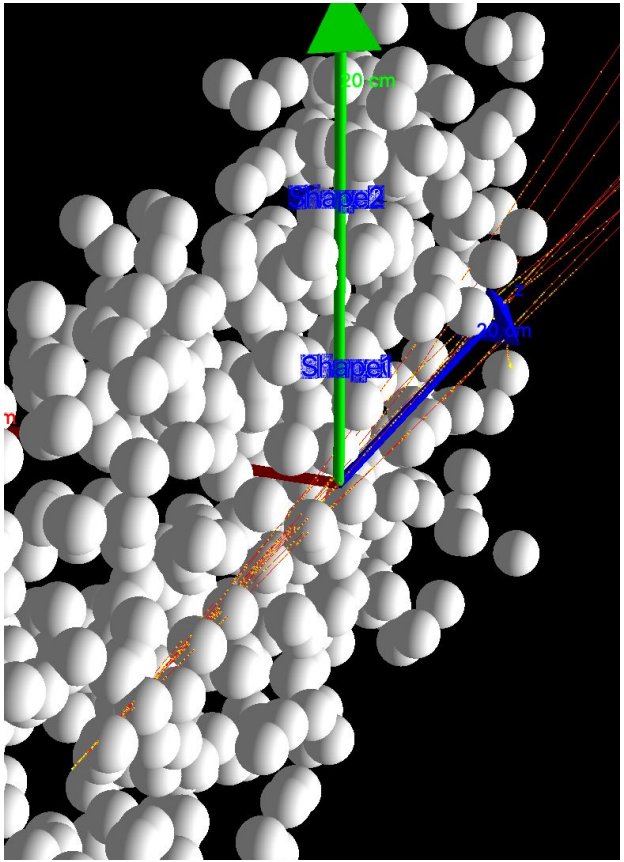


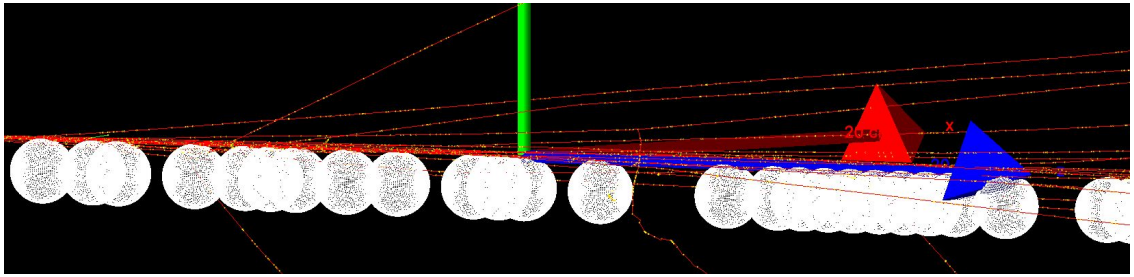
gammas

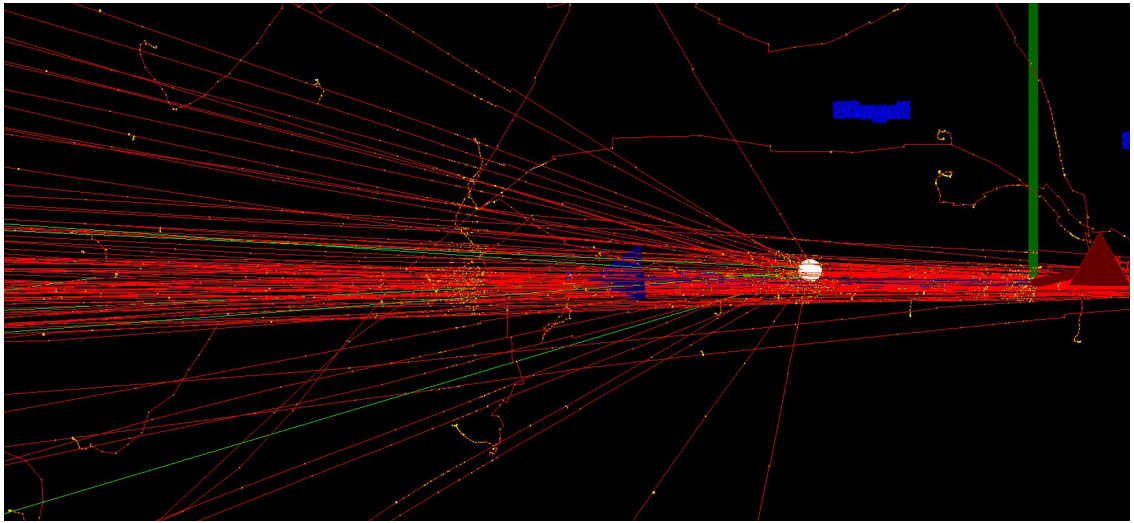
e-

zemlianskay.d@phystech.edu

Avalanche Narrowing







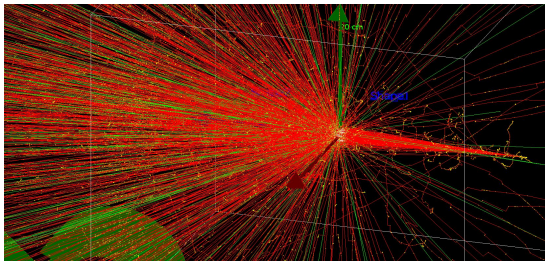
The narrowing of the beam is also visible from the visualization of the process.

zemlianskay.d@phystech.edu

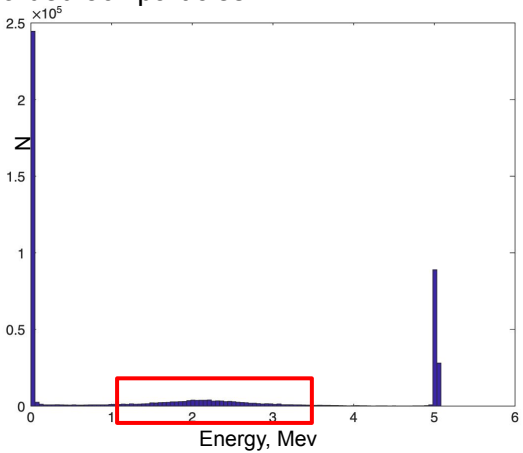
1 hydrometeor

- launch particles with an energy of 5 MeV

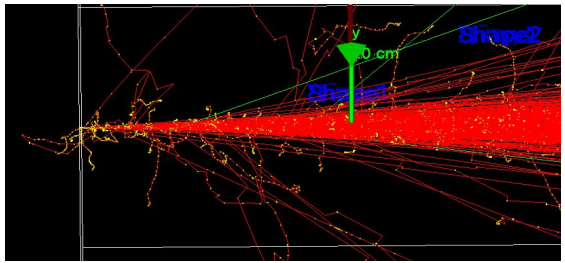
1 hydrometeor, R= 1 cm



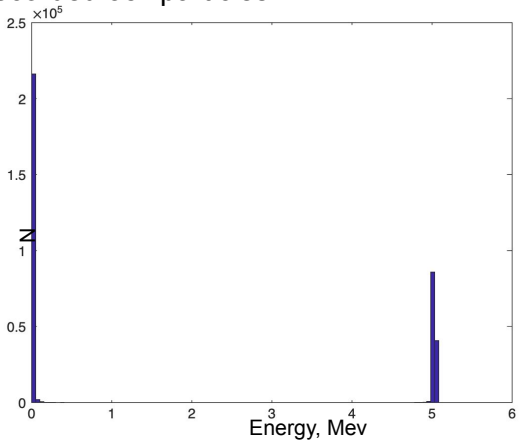
recorded 50к particles



0 hydrometeor



recorded 35к particles



When scattered by one hydrometer, an increase in the number of particles is observed, as well as changes in the spectrum

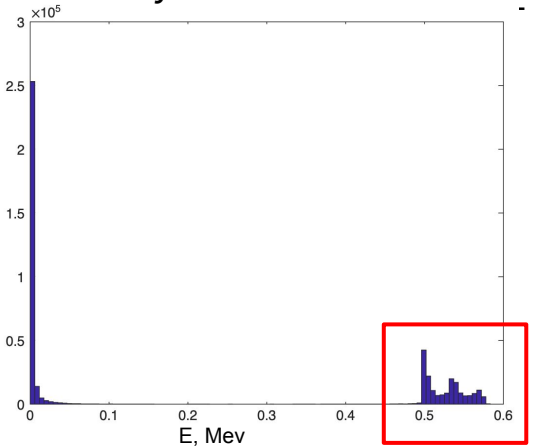
Hydrometers increase the number of particles capable of escaping under the influence of an electric field, as a result, we see an increase in the number of particles and a decrease in the growth length of the avalanche

zemlianskay.d@phystech.edu

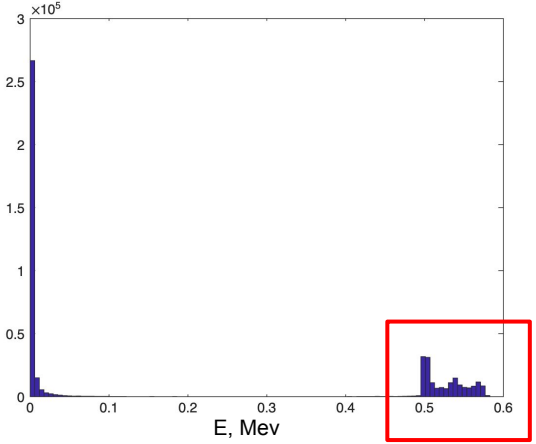
1 hydrometeor

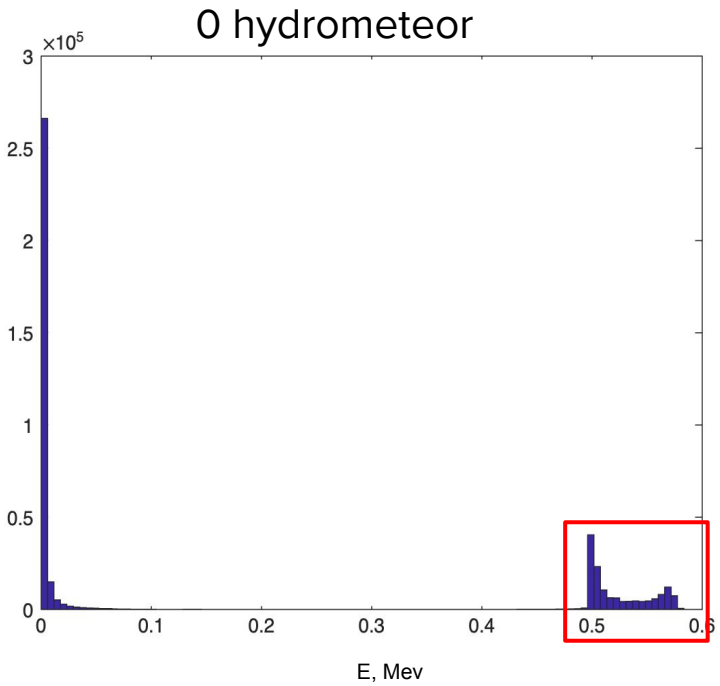
- the model with a starting particle with an energy of 500 keV
- the spectrum also differs in the case of the presence of a hydrometeor and without it

R = 1 cm



R = 1 mm





zemlianskay.d@phystech.edu

Modified material

We also tested another option for modeling hydrometeors - changing the material of the volume, because:

- we can simply change the material in the GEANT4
- many small hydrometeors equals to a homogeneous material
- it will make calculations faster (cell with modified material is simpler than a cell with hundreds of thousands of balls)

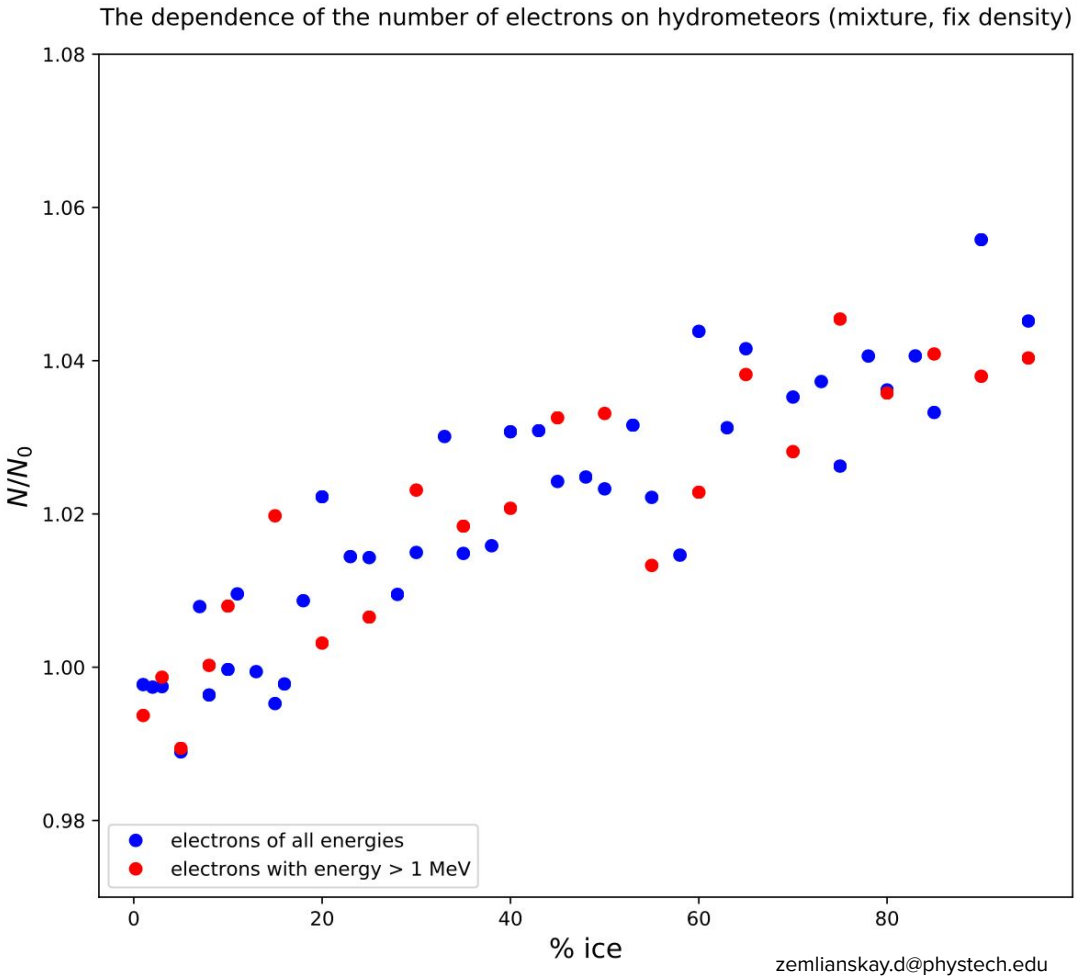
We create a material as a mixture of two components -
ice (water with a high density) and air, the total density of the material can be set to a fixed

zemlianskay.d@phystech.edu

Fixed density

- fixed density, but with a change in the ice component in the material (like only change the atomic composition)

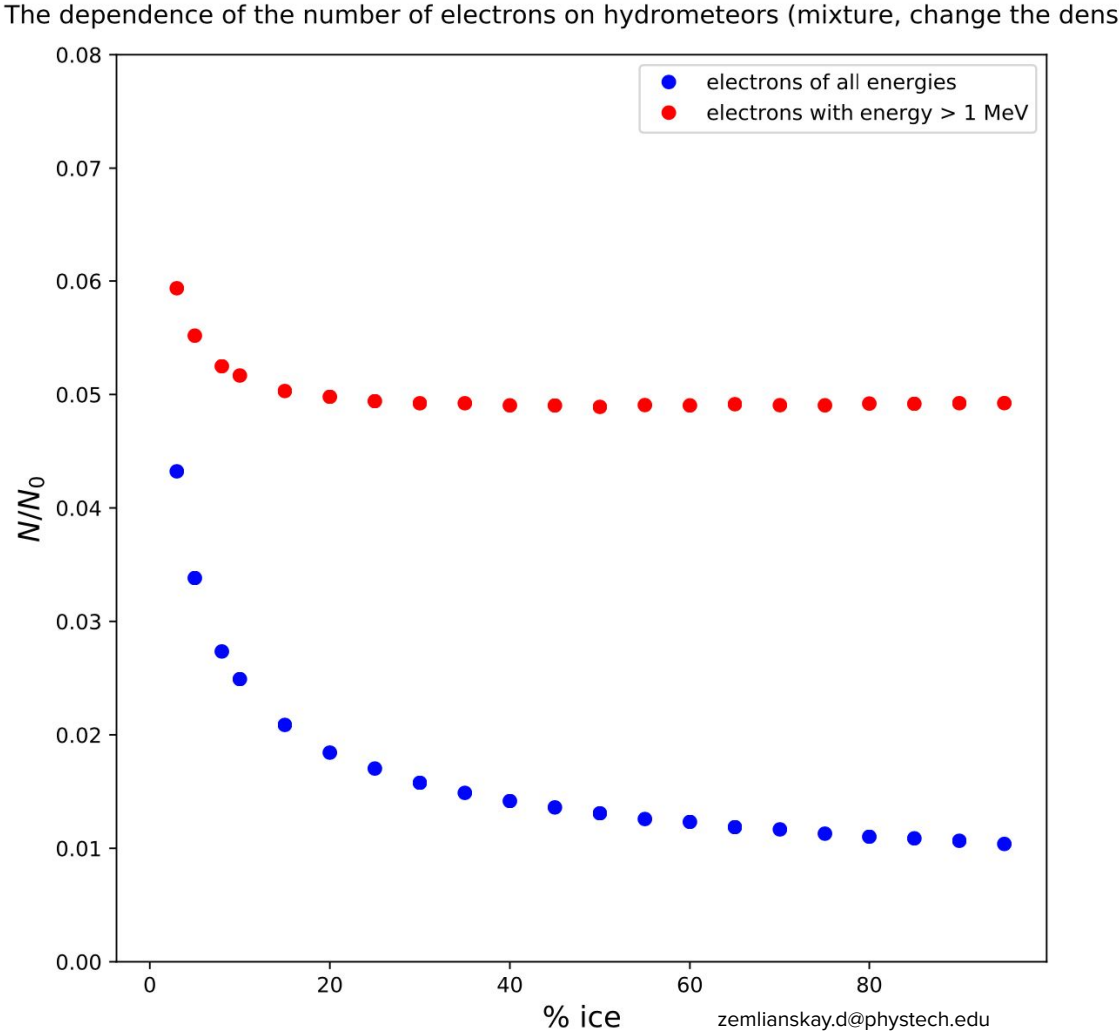
- the number of particles has decreased for realistic values of the percentage of hydrometeors



zemlianskay.d@phystech.edu

With density change

The second approach is also to change the density of the volume, however, even a small percentage of the added hydrometeors changes the density of the system, hence the particle flux decays very quickly.



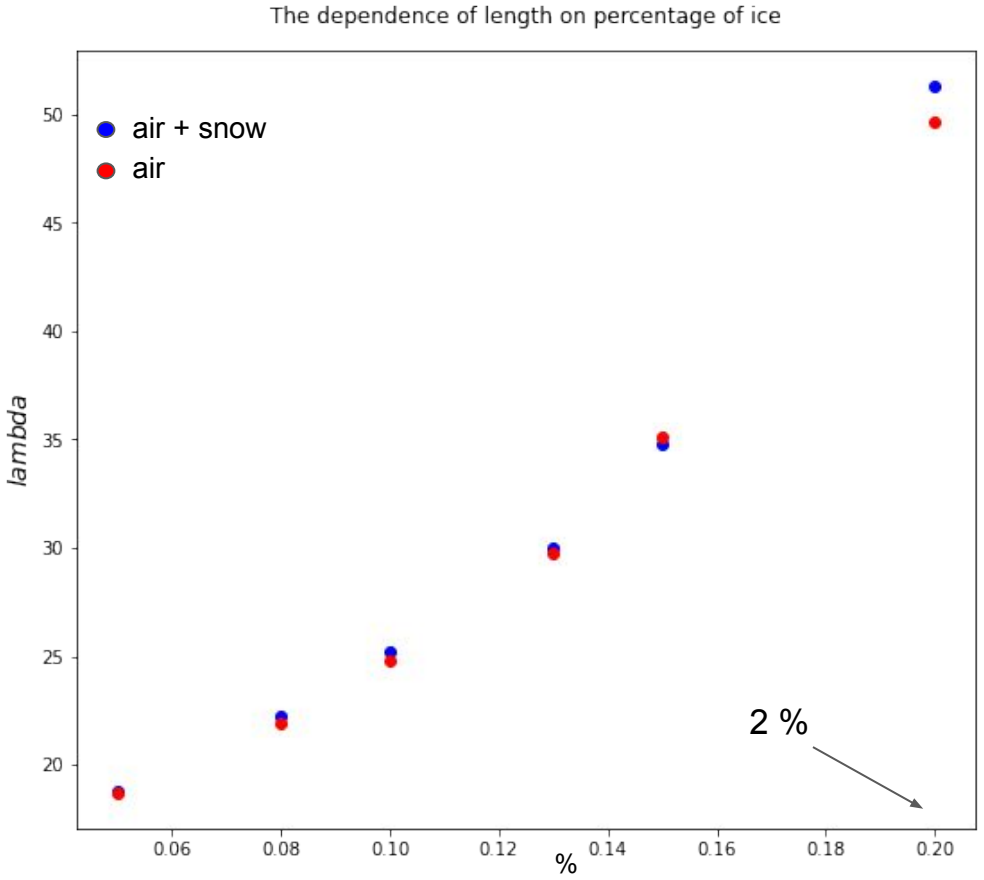
With density change

- we increased the field to 700 kV/m (where electrons can escape even with the addition of 2 percent of hydrometeors)

- density increases as the sum of the proportions of snow and air

- X-axis - percentage of ice (where only air is the percentage of ice density, for example 0.414 * 0.99 + 0.01 * 900)

- difference between the blue and red dots on the graph is only in the different component composition - the presence of water in the material. Their density will be the same.



Based on the picture, we found that the model with the modified material can only increase the growth length of the avalanche by a few meters.

zemlianskay.d@phystech.edu

Conclusions

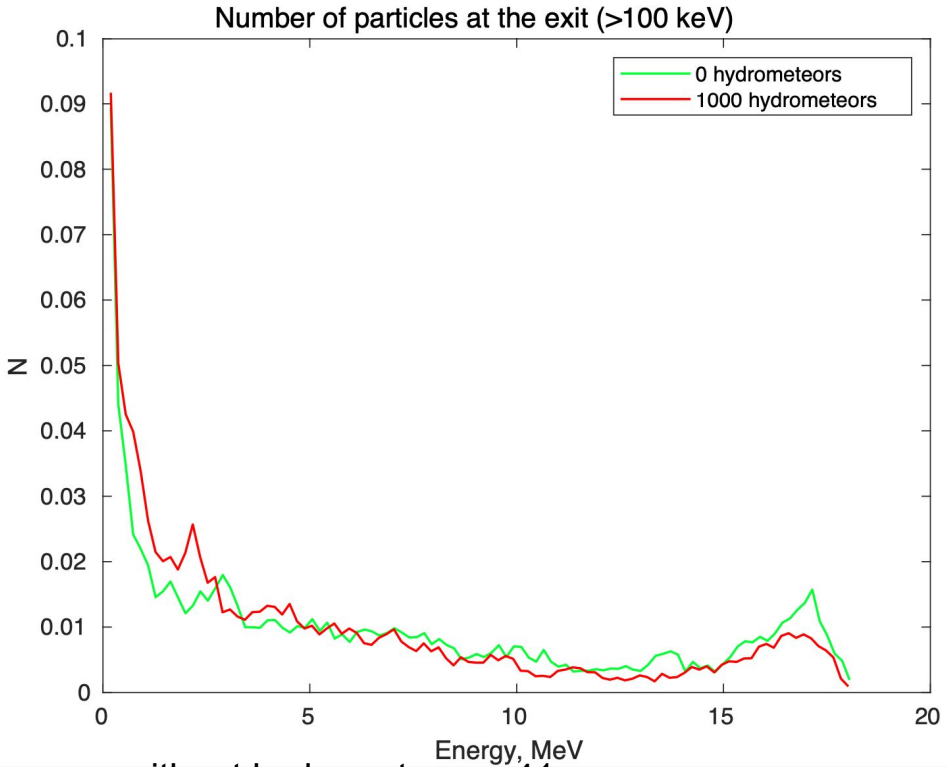
- due to hydrometeors, runaway electrons multiply strongly, and then accelerate between ice balls, this happens locally
- we can use hydrometeors up to 3-4 cm
- as the avalanche spreads, it narrows
- adding hydrometeors reduces growth length by 20%
- modified material approximation does not correspond to volumetric ice balls
- the decrease in the avalanche growth length in the case of volumetric hydrometeors is associated with the difference in densities (900 kg/m3 and 0.414 kg/m3 for ice and air) and the possibility of electrons to gain energy between collisions (due to their small number)

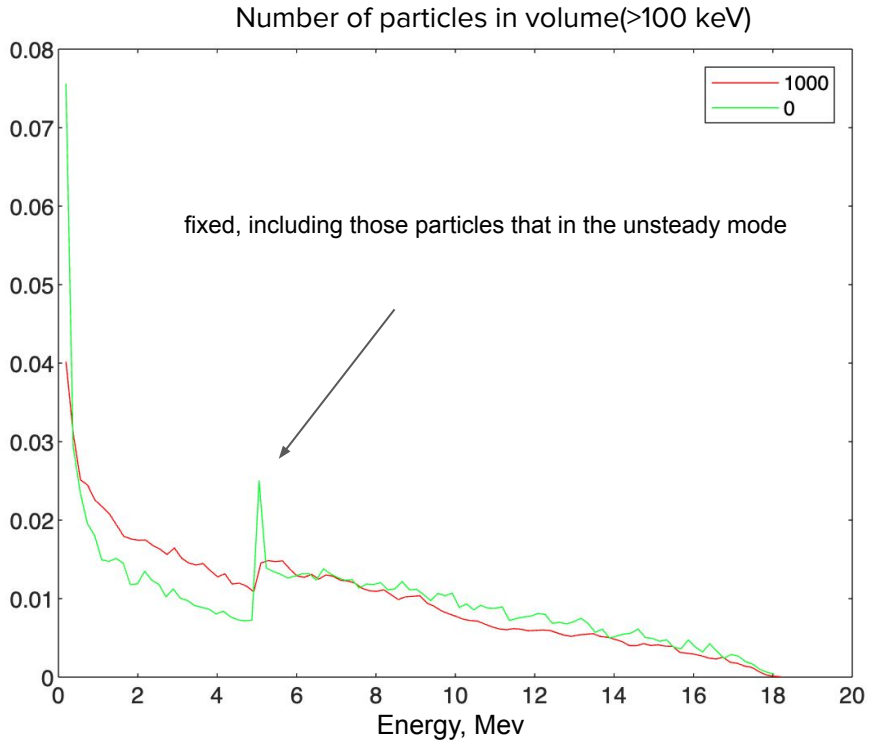
zemlianskay.d@phystech.edu

Thank you for your attention!

Spectrum

Launching 5 MeV electrons





without hydrometeors - 41к

with hydrometeors 58к

zemlianskay.d@phystech.edu