

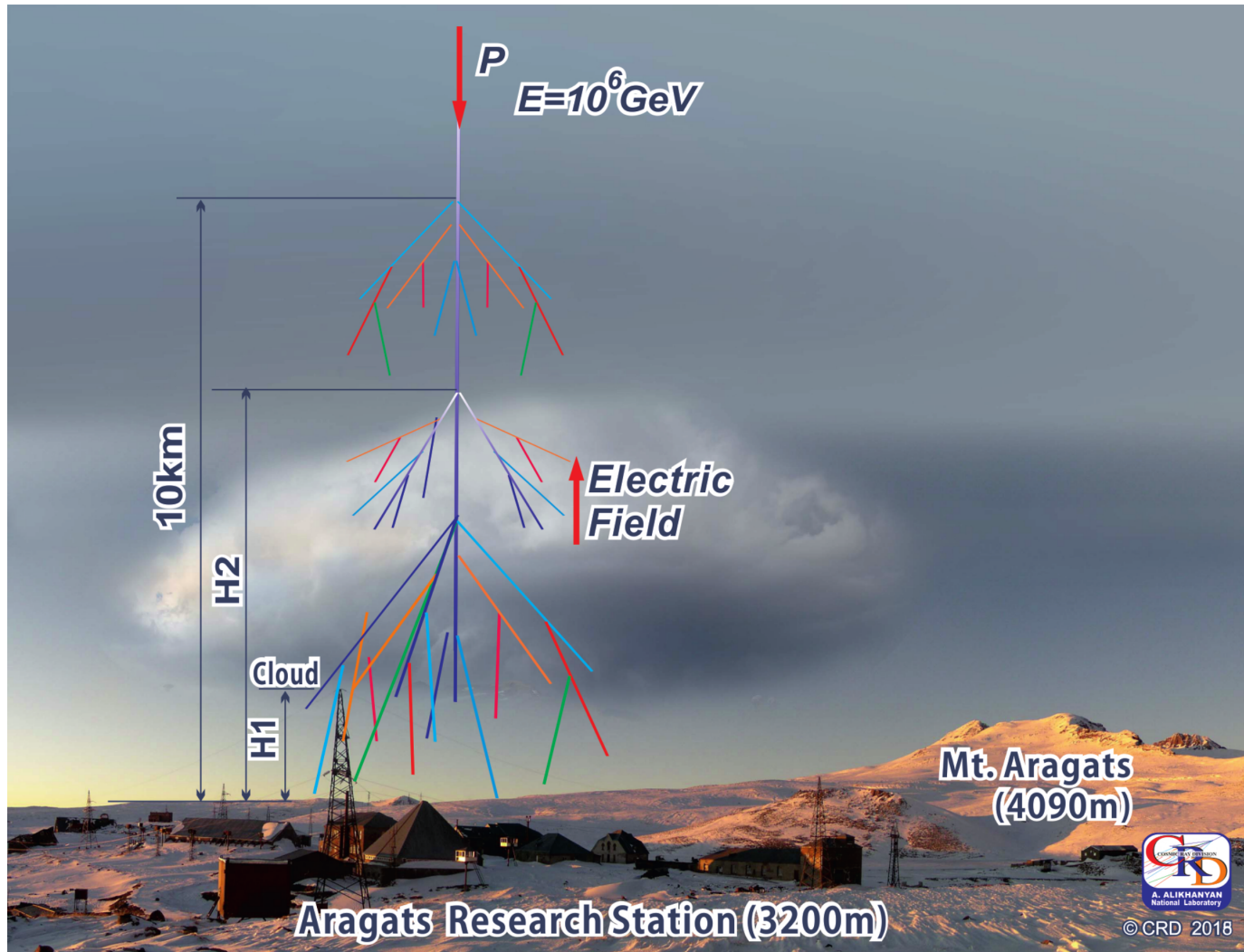


TGE at UHECR energies

Roberta Colalillo
Università degli Studi di Napoli "Federico II"

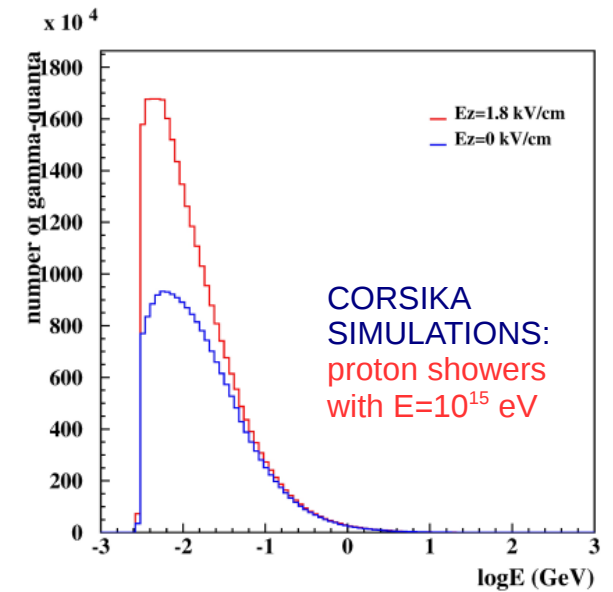
NOR AMBERD, Byurakan,
14/10/2019, TEPA 2019

Theoretical Models

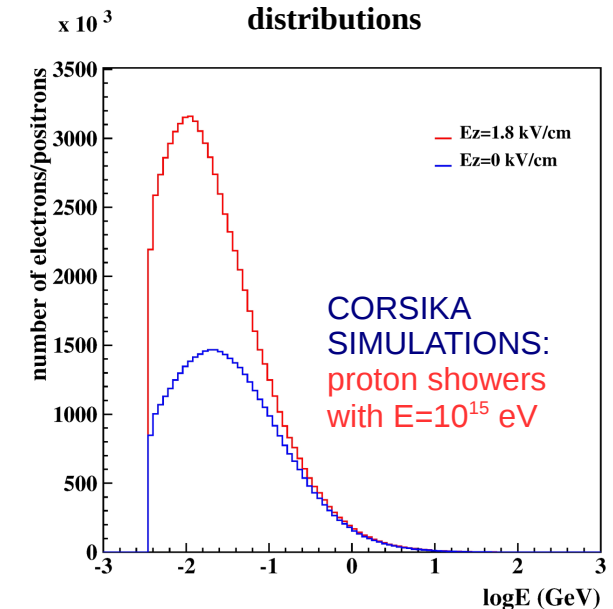


Cartoon demonstrating electron acceleration and multiplication in the electric field of the lower dipole of the thundercloud

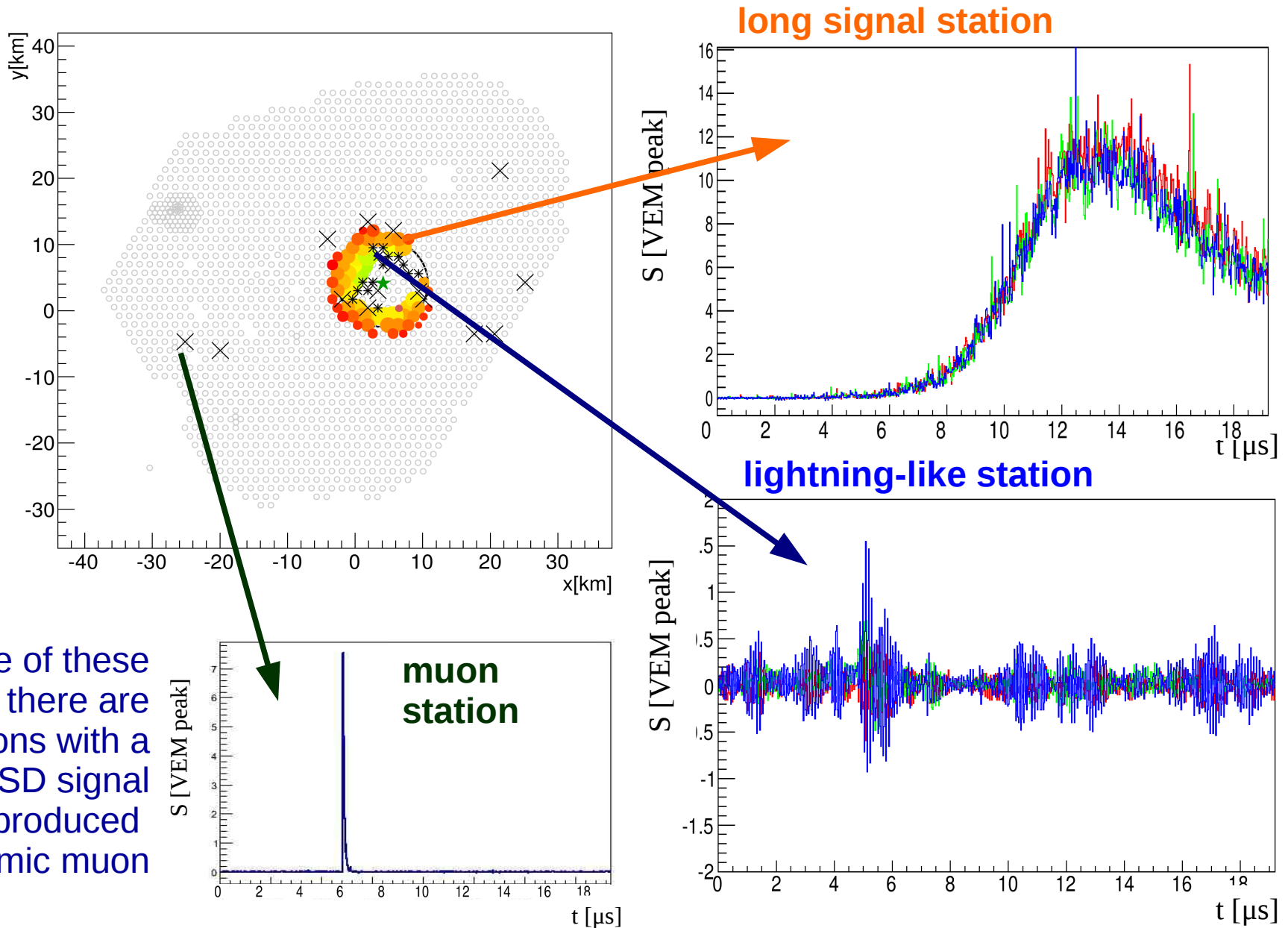
Secondary photons energy distributions



Secondary electrons/positrons energy distributions

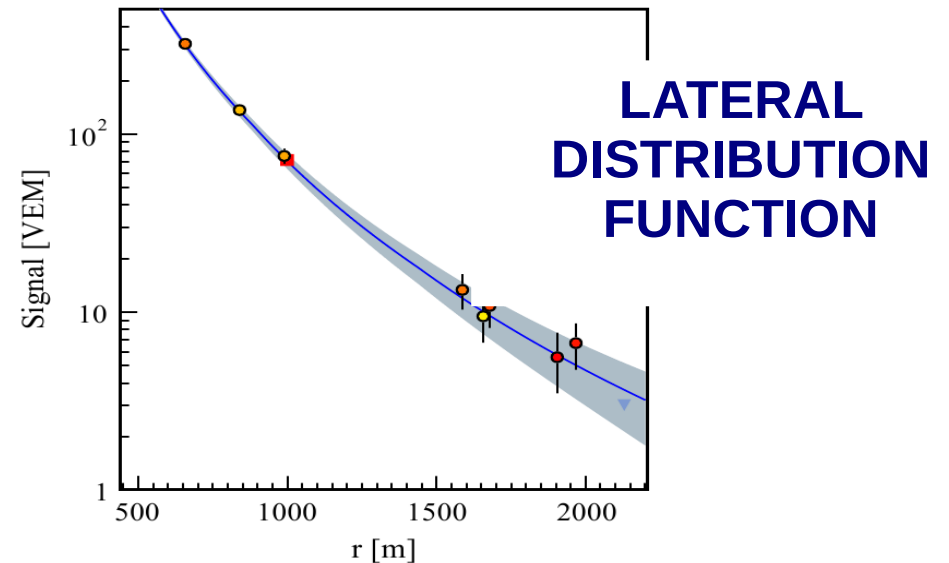
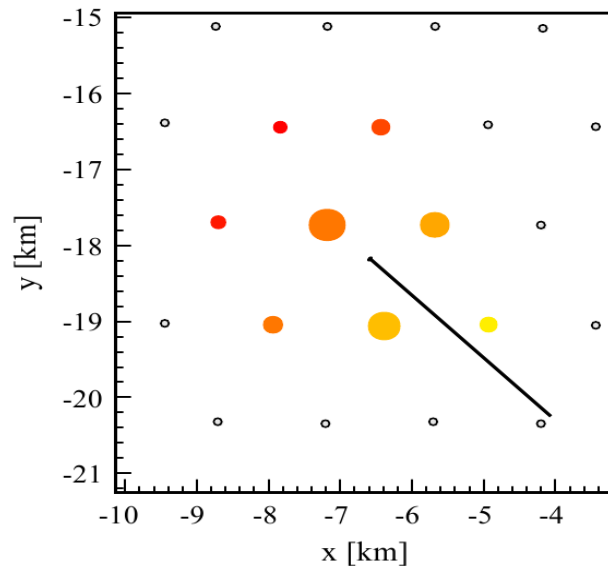


Auger SD Exotic Events

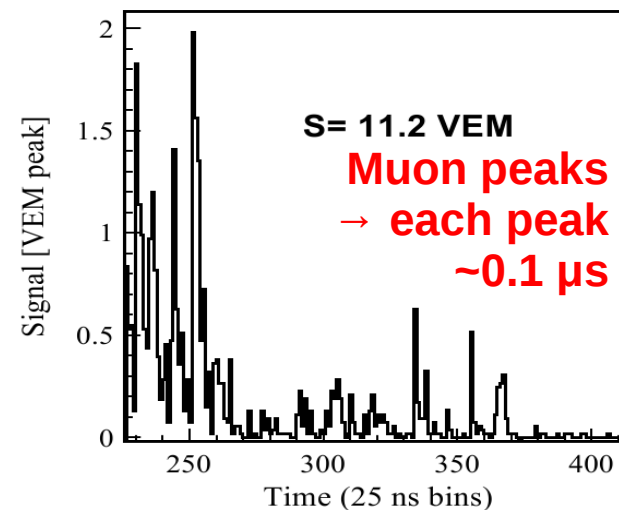
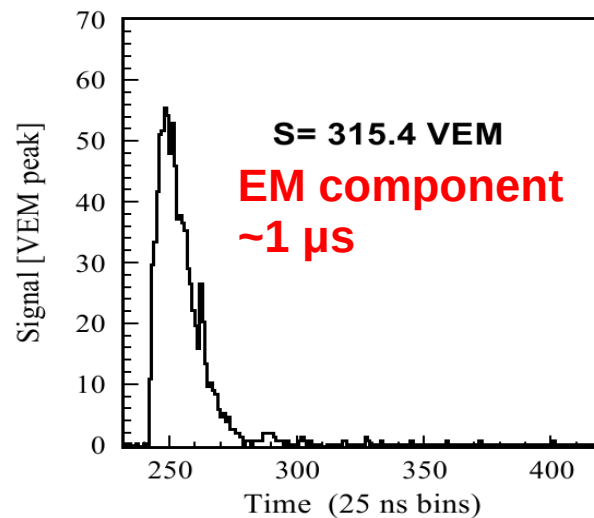


Cosmic Ray Signal in the Auger SD

Shower with $E=3 \times 10^{19} \text{ eV}$, $\theta=28^\circ$



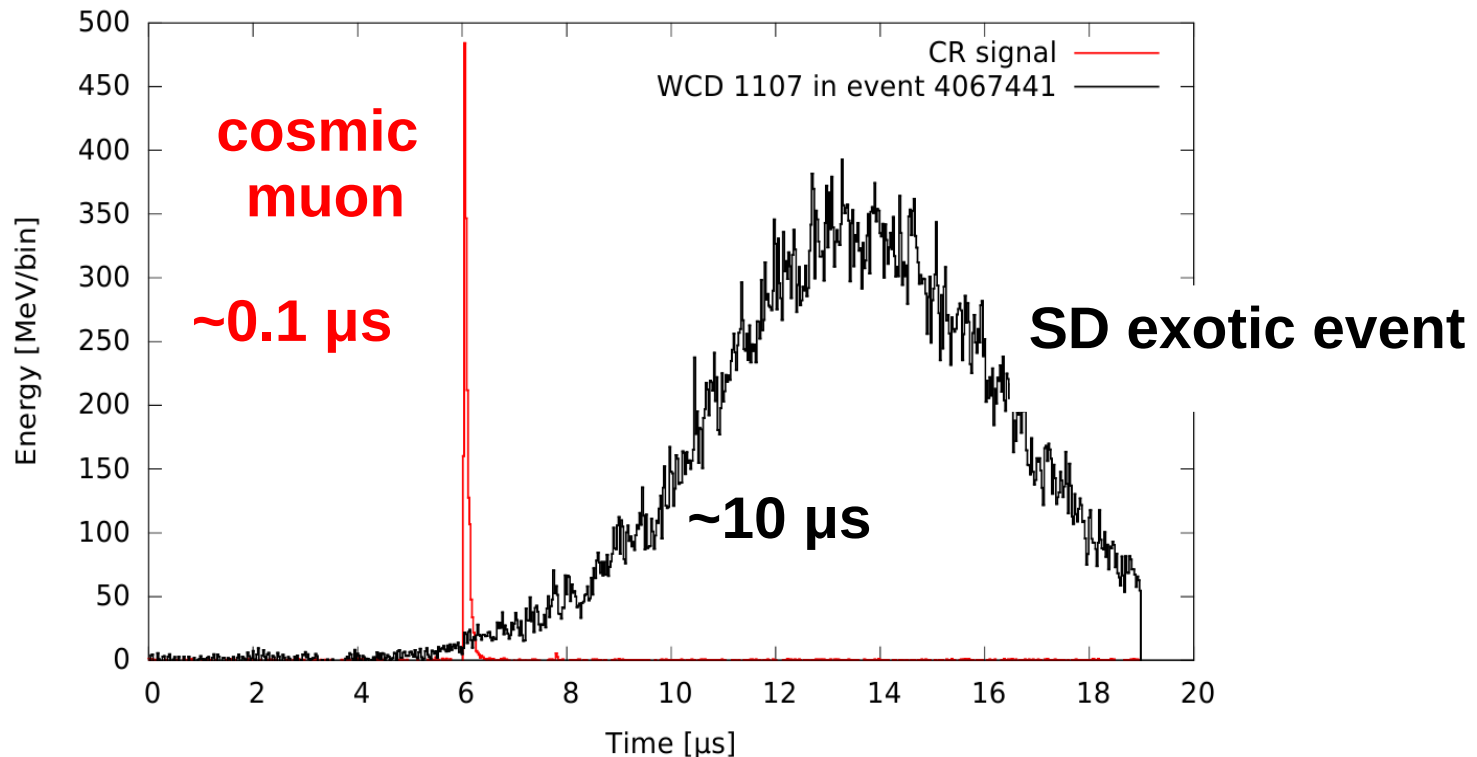
Station at
650 m from
the shower
core



Station at
1780 m from
the shower
core

Auger SD Exotic Events

- Larger time scale ($\sim 10 \mu\text{s}$);
- Many triggered detectors arranged in circular shape;
- Some stations have lightning induced signal
→ high frequency noise



Simulation Conditions

Production of CORSIKA showers activating the EFIELD option:

Primary: **proton** - iron, oxygen

Energy: 10^{19} eV - 10^{17} and 10^{18} eV, Zenith: 0° - 7° , 15° , 22° , 30° , 45° , 60°

Thinning: 10^{-3}

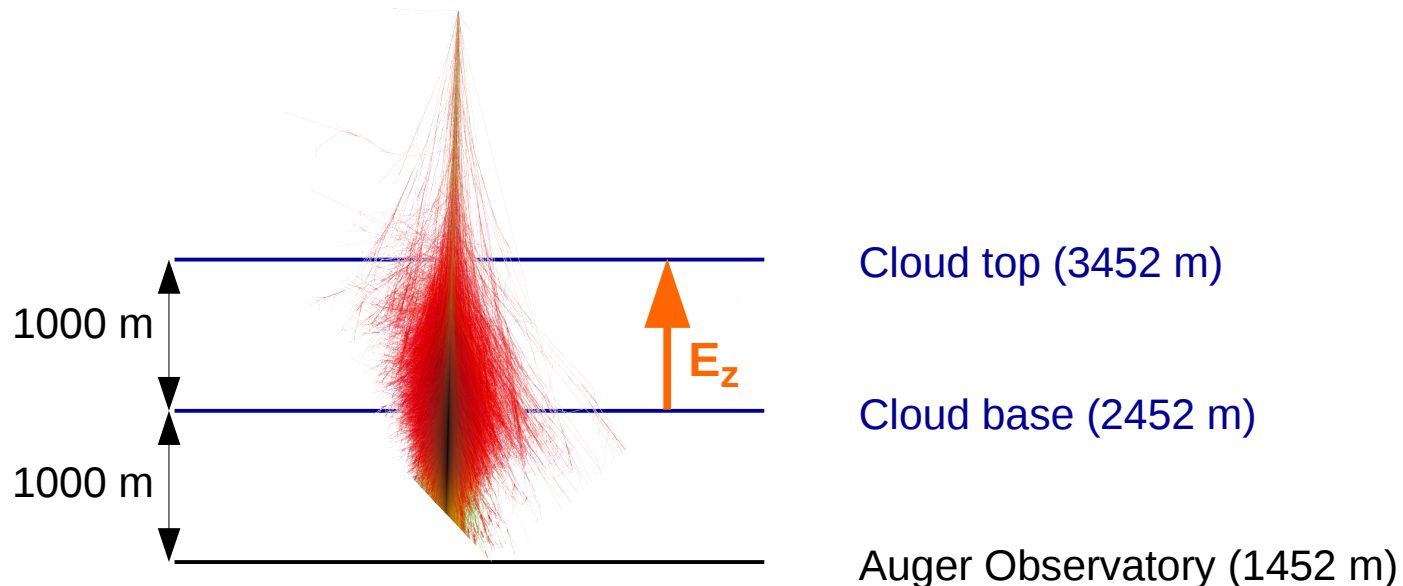
HE model: QGSJET-II.04

LE model: fluka

E_z → from 1.8 to 2.5 kV/cm → step 0.1

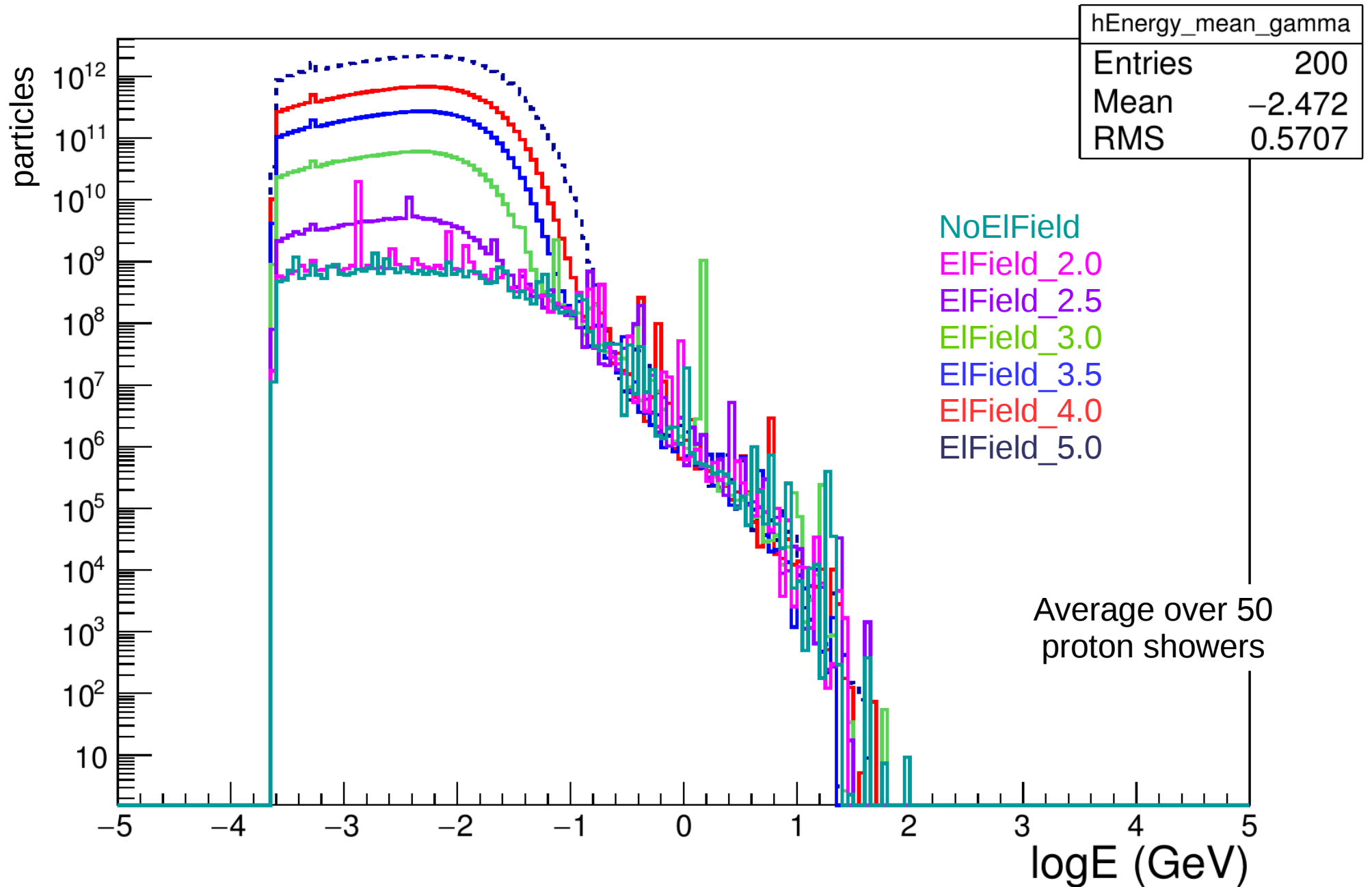
E_z → from 2.5 to 4 kV/cm → step 0.5 + 5 kV/cm (NO measured value)

Cloud base = 2452 m → 1 km above the Auger site – 0.5, 2, 3, 4, 5, 6 km



Gamma at the Observation Level

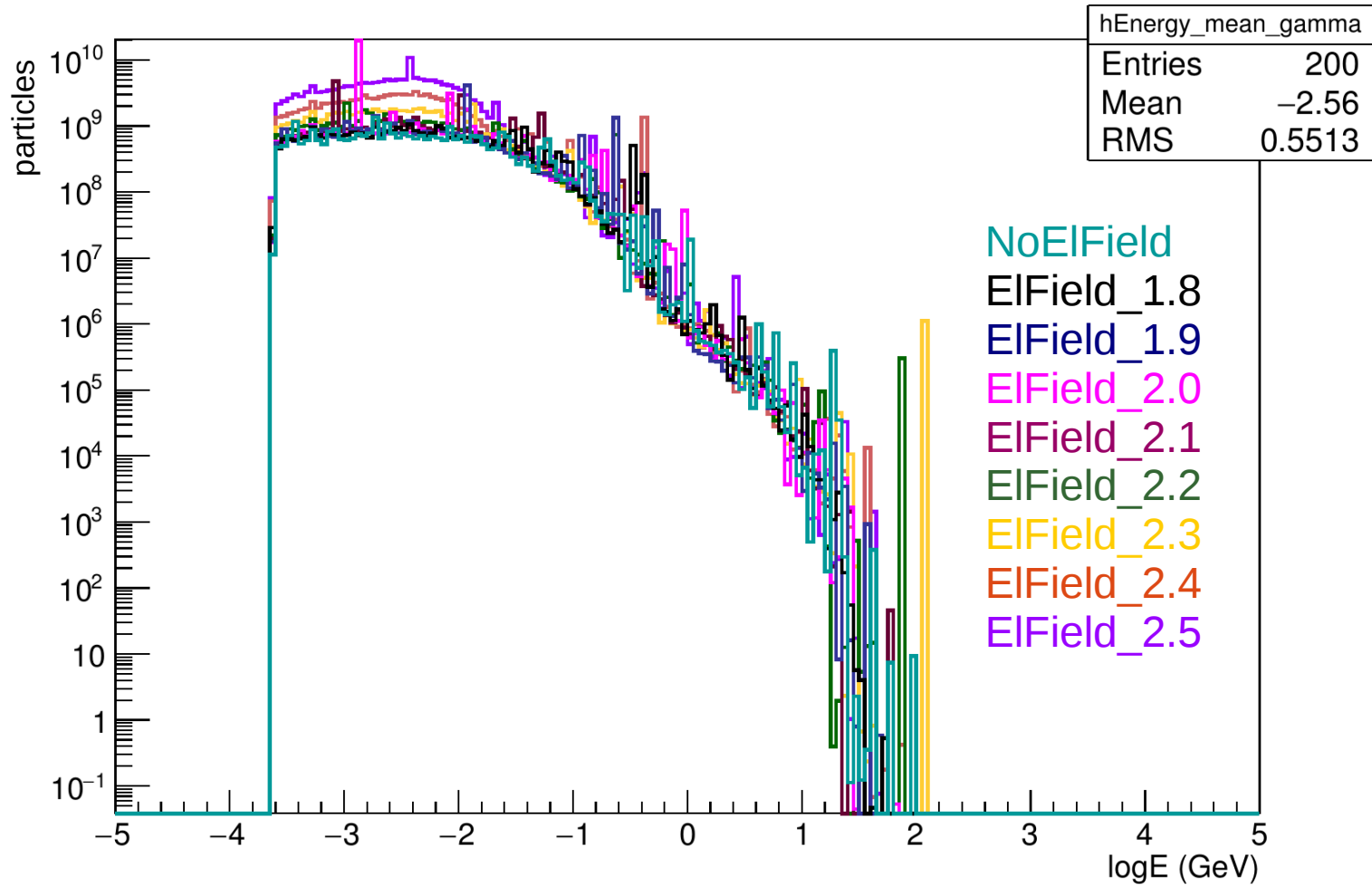
log(E) for gamma



Gamma at the Observation Level

Scan 0.1 from 1.8 to 2.5 kV/cm

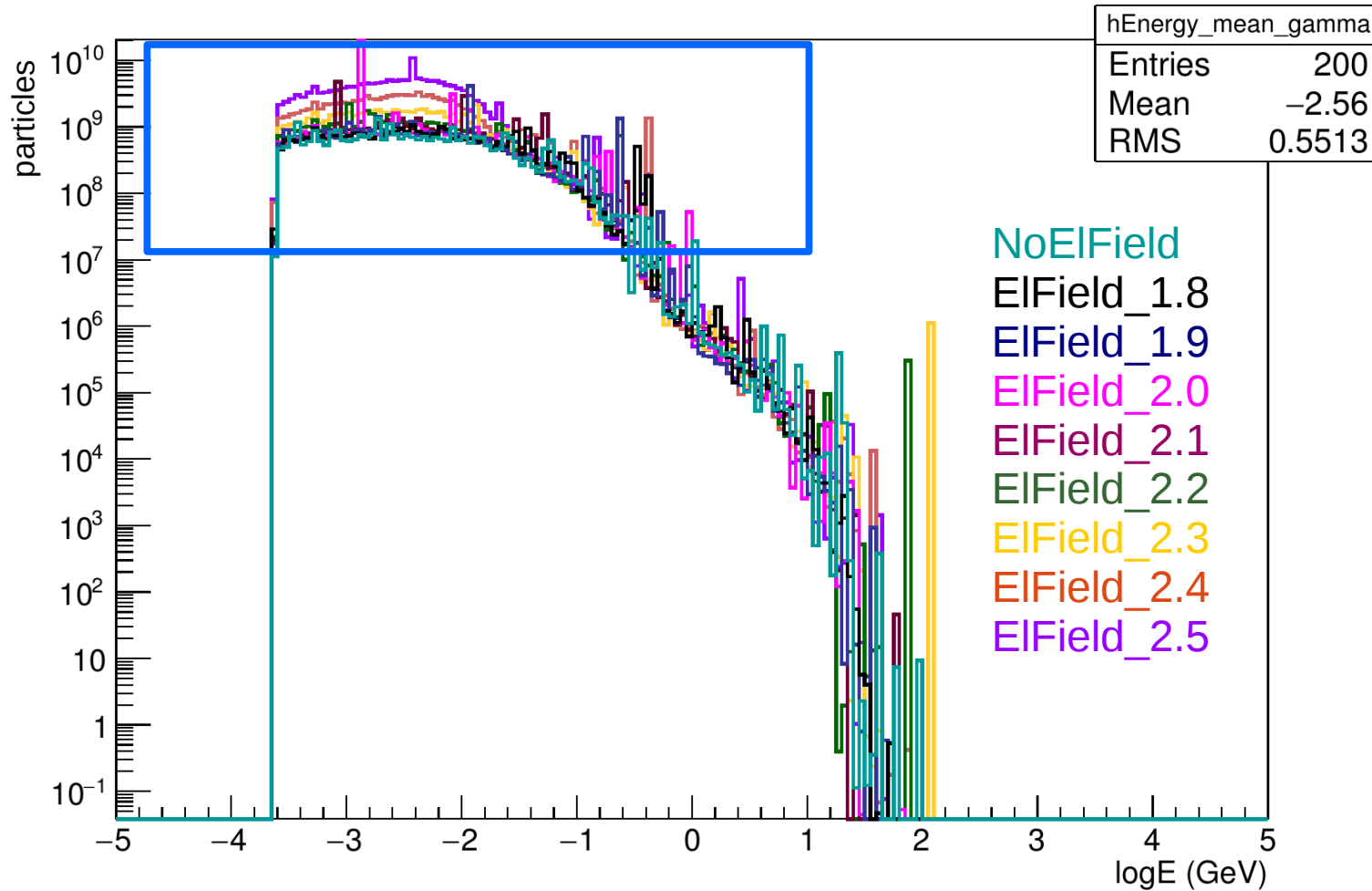
log(E) for gamma



Gamma at the Observation Level

Scan 0.1 from 1.8 to 2.5 kV/cm

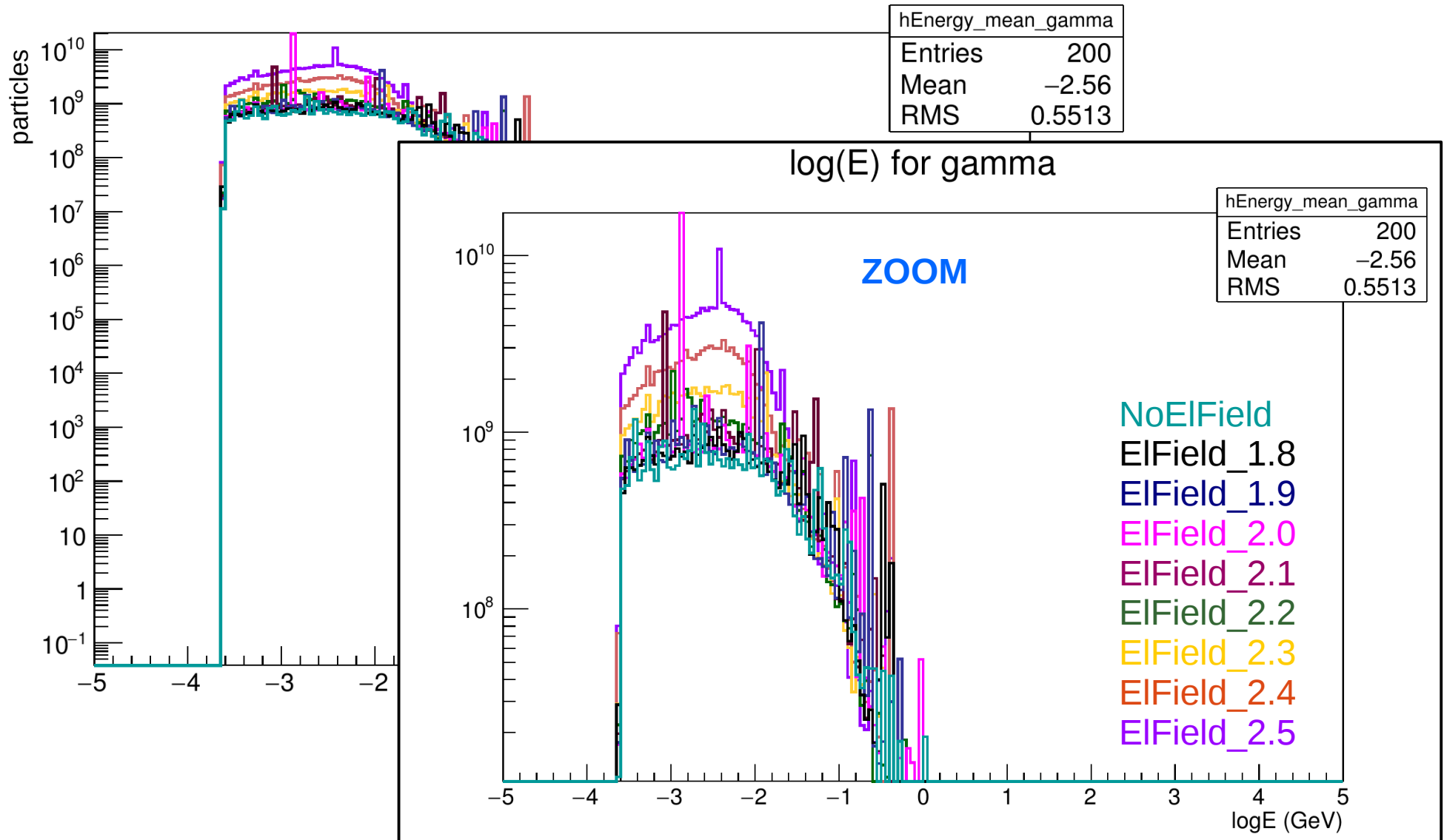
log(E) for gamma



Gamma at the Observation Level

Scan 0.1 from 1.8 to 2.5 kV/cm

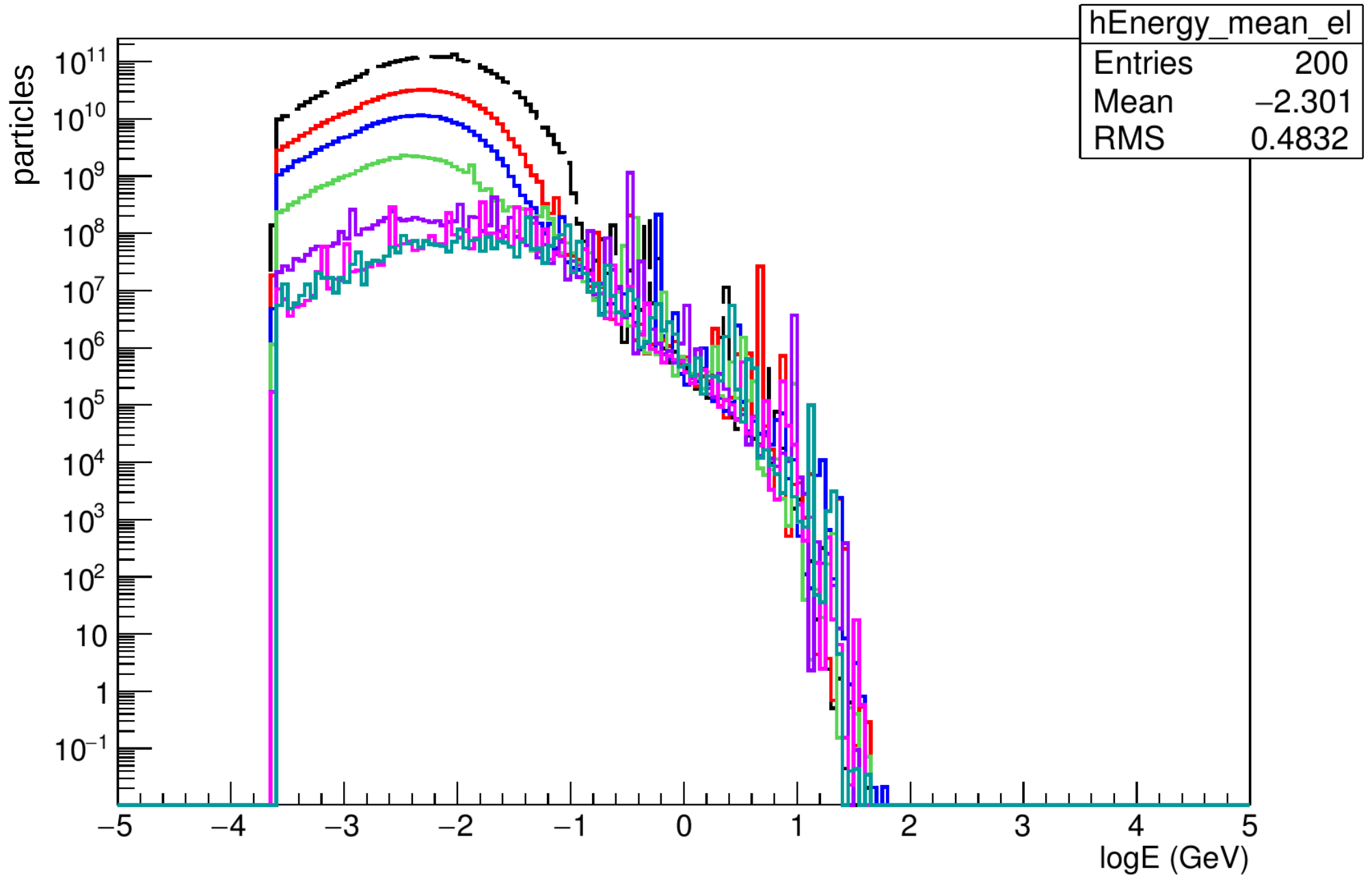
log(E) for gamma



We have the first big enhancement in the particle flux with $E = 2.3$ kV/cm.

e-/e+ at the Observation Level

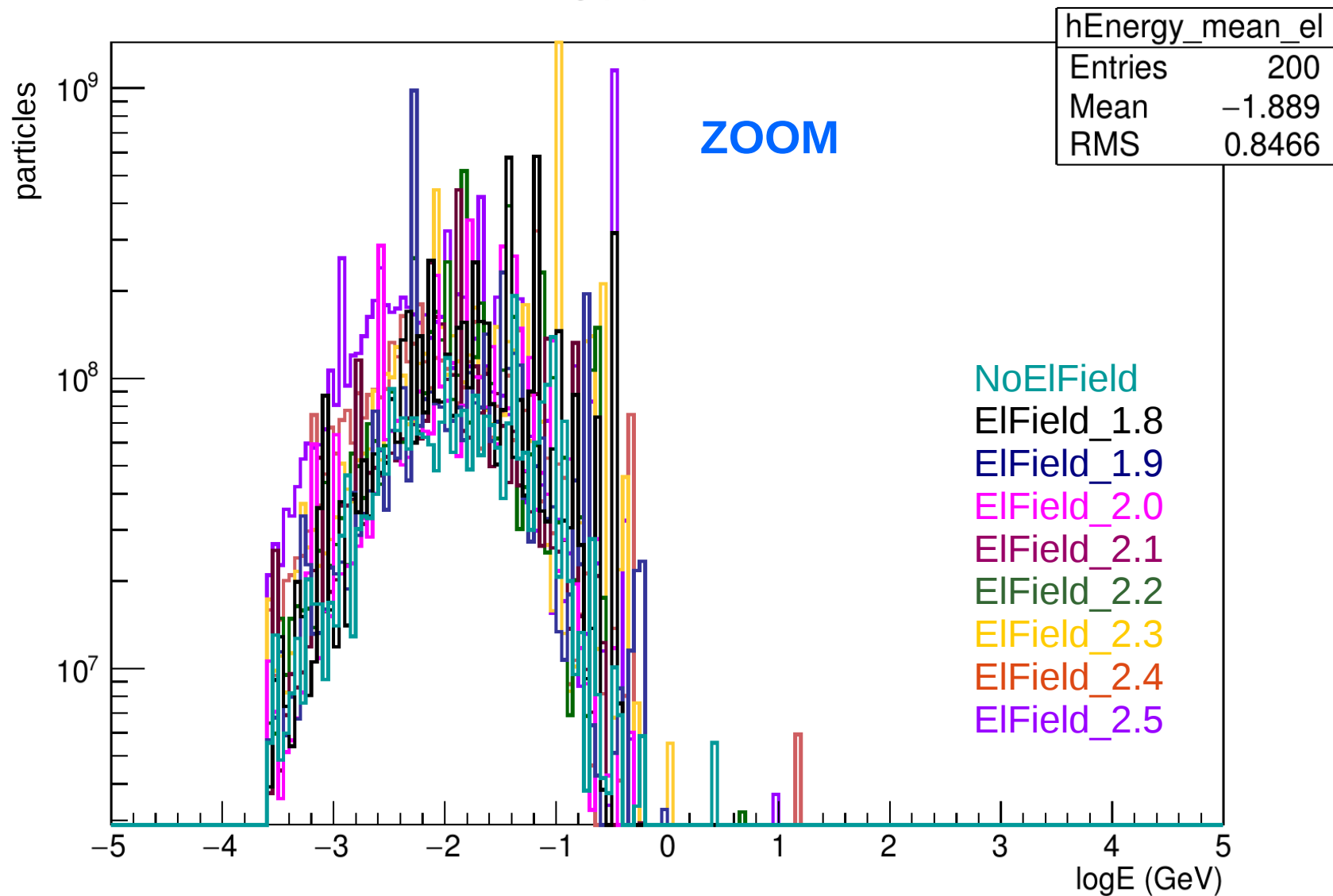
log(E) for EM



e-/e+ at the Observation Level

Scan 0.1 from 1.8 to 2.5 kV/cm

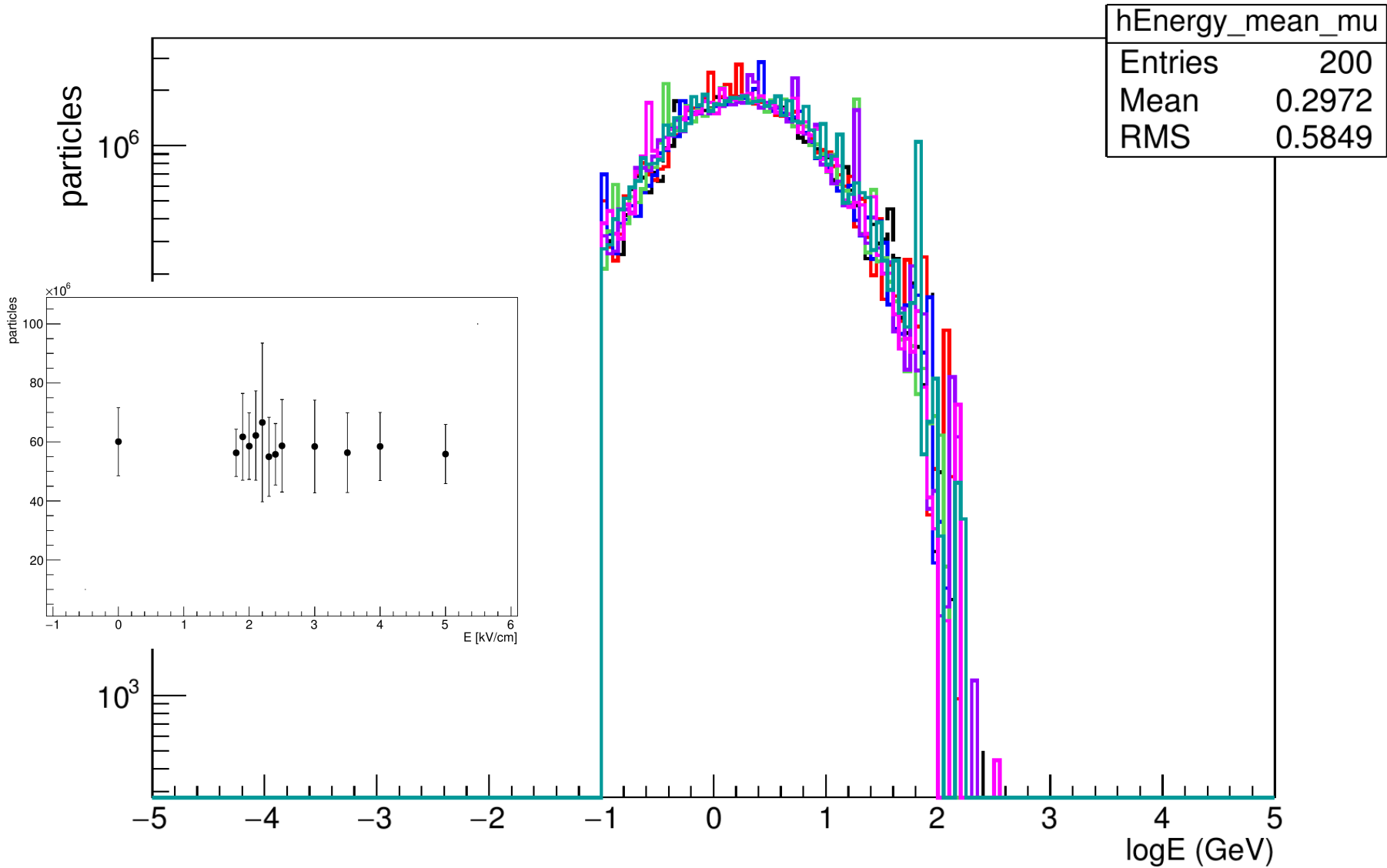
log(E) for EM



We can see an enhancement starting from $E = 2.5$ kV/cm.

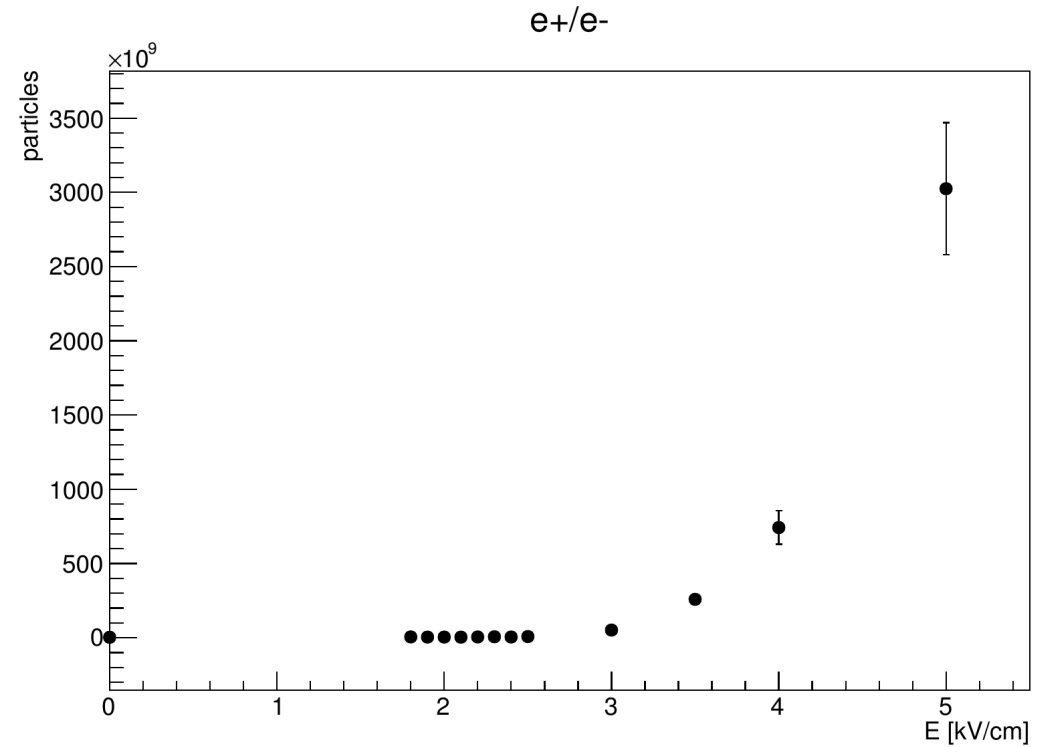
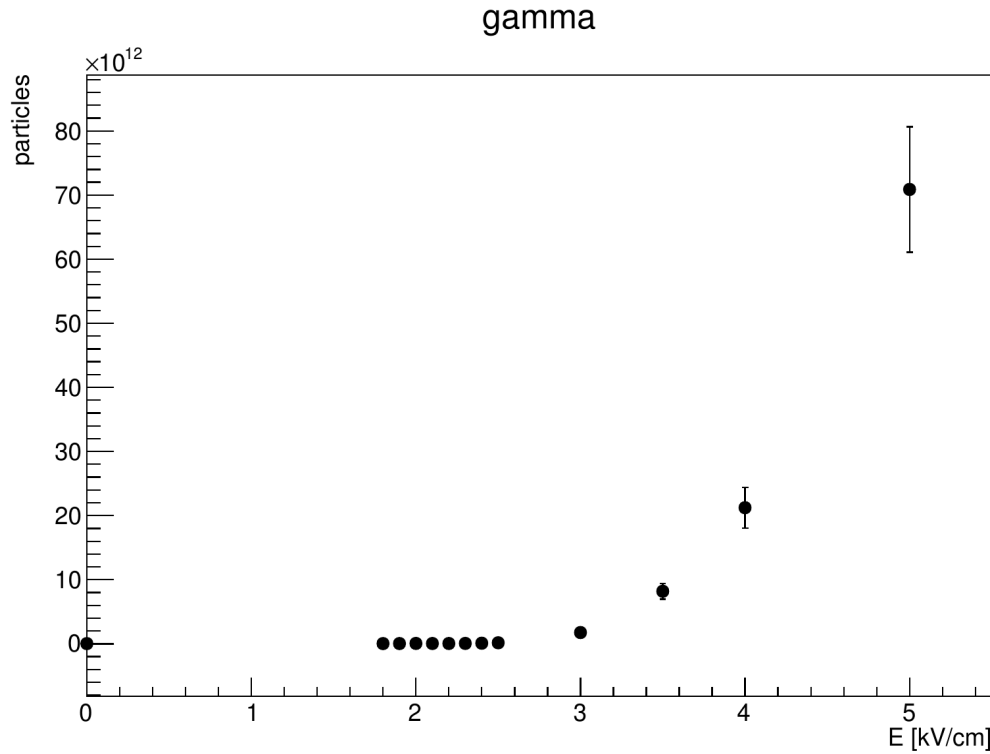
Muon at the Observation Level

log(E) for mu



NO ENHANCEMENT. The same was observed at lower energies.

Particle Number Vs Efield



Nearly Exponential Increase

NO El Field → gamma, e-e+, μ : 3.34e+10, 2.90e+09, 6.01e+07

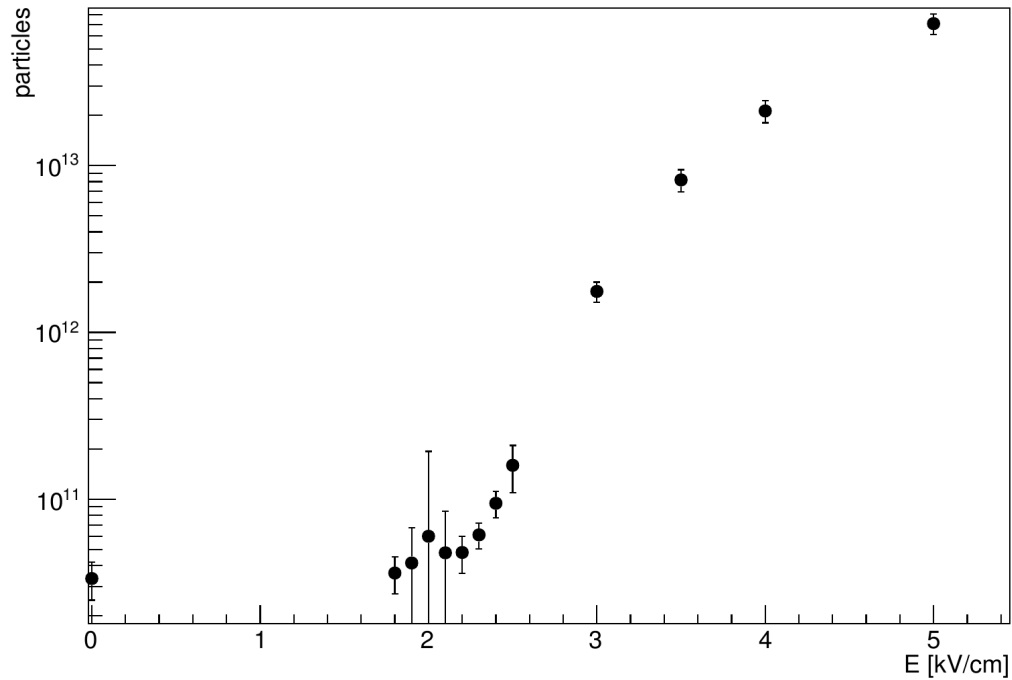
·
·
·

E = 4 kV/cm → gamma, e-e+, μ : 2.12e+13, 7.42e+11, 5.85e+07

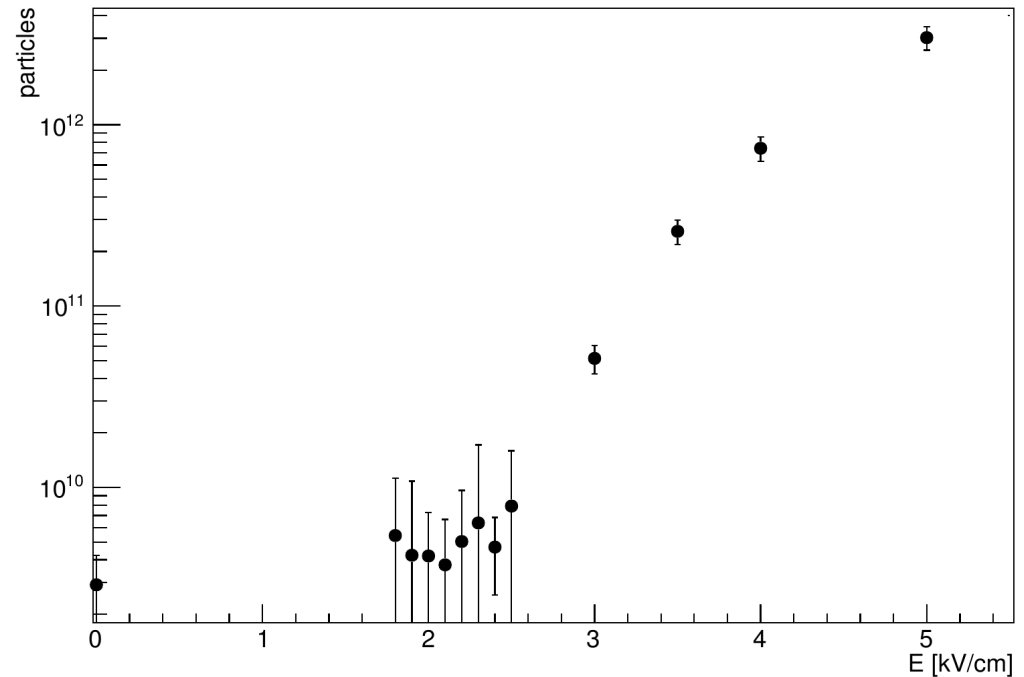
E = 5 kV/cm → gamma, e-e+, μ : 7.09e+13, 3.02e+12, 5.59e+07

Particle Number Vs Efield

gamma



e+/e-



Nearly Exponential Increase

NO EI Field → gamma, e-e+, μ : 3.34×10^{10} , 2.90×10^9 , 6.01×10^7

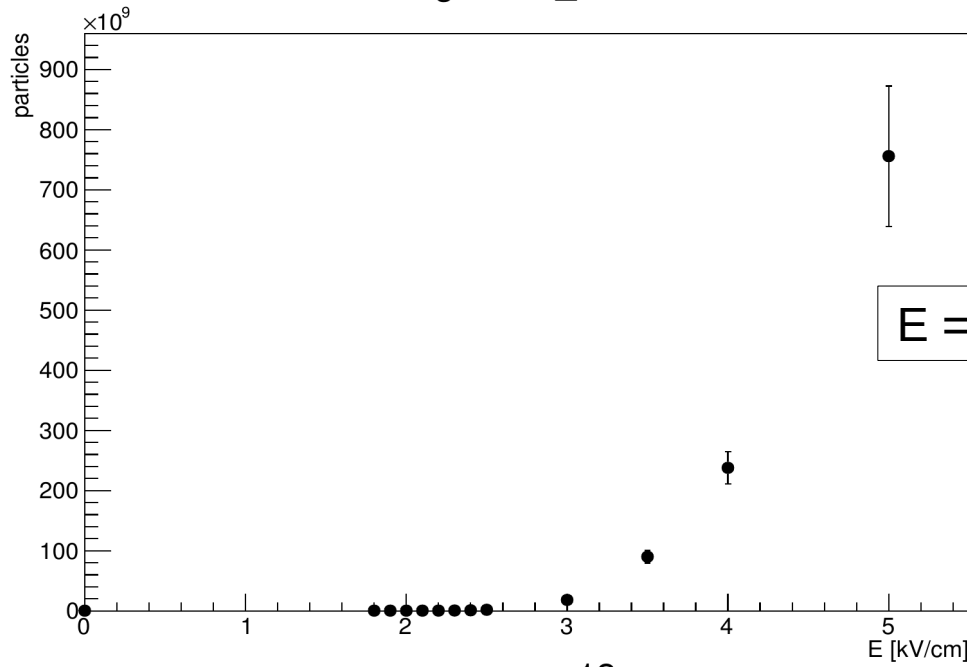
·
·
·

E = 4 kV/cm → gamma, e-e+, μ : 2.12×10^{13} , 7.42×10^{11} , 5.85×10^7

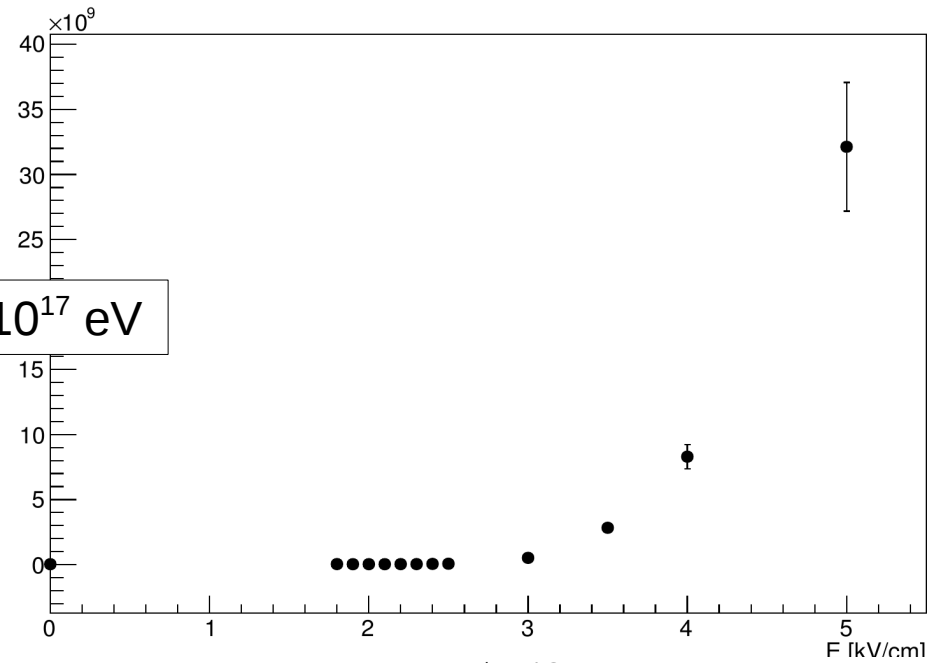
E = 5 kV/cm → gamma, e-e+, μ : 7.09×10^{13} , 3.02×10^{12} , 5.59×10^7

Particle Number Vs Efield

gamma_17

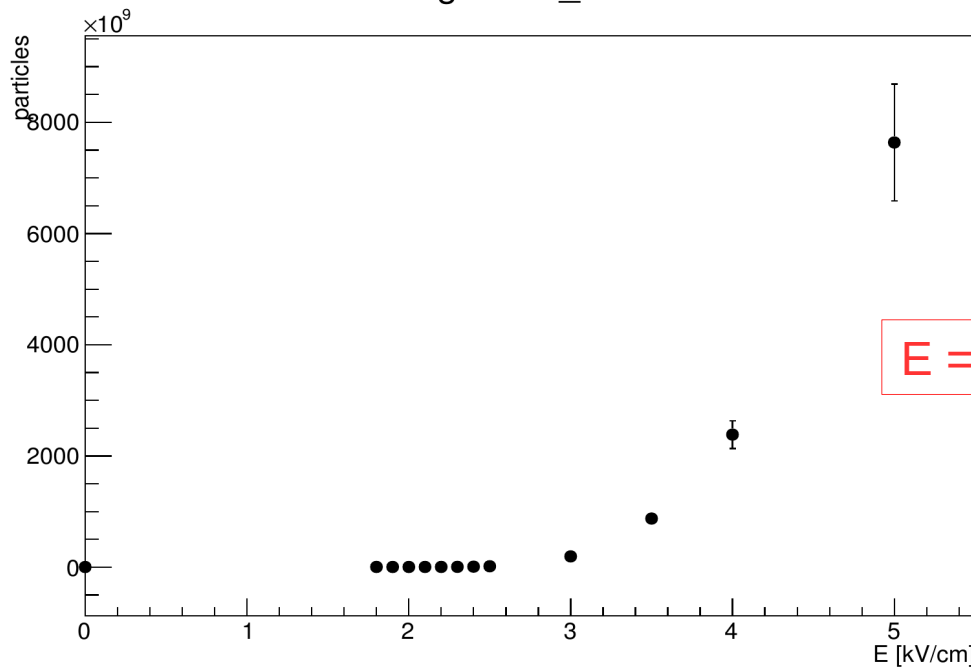


e+/e- 17

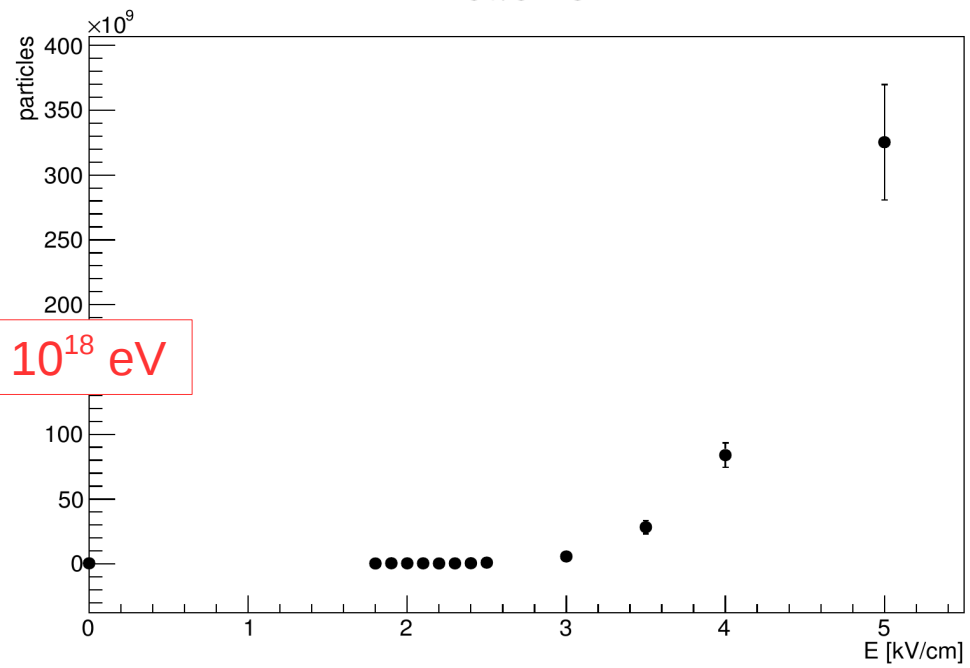


E = 10^{17} eV

gamma_18

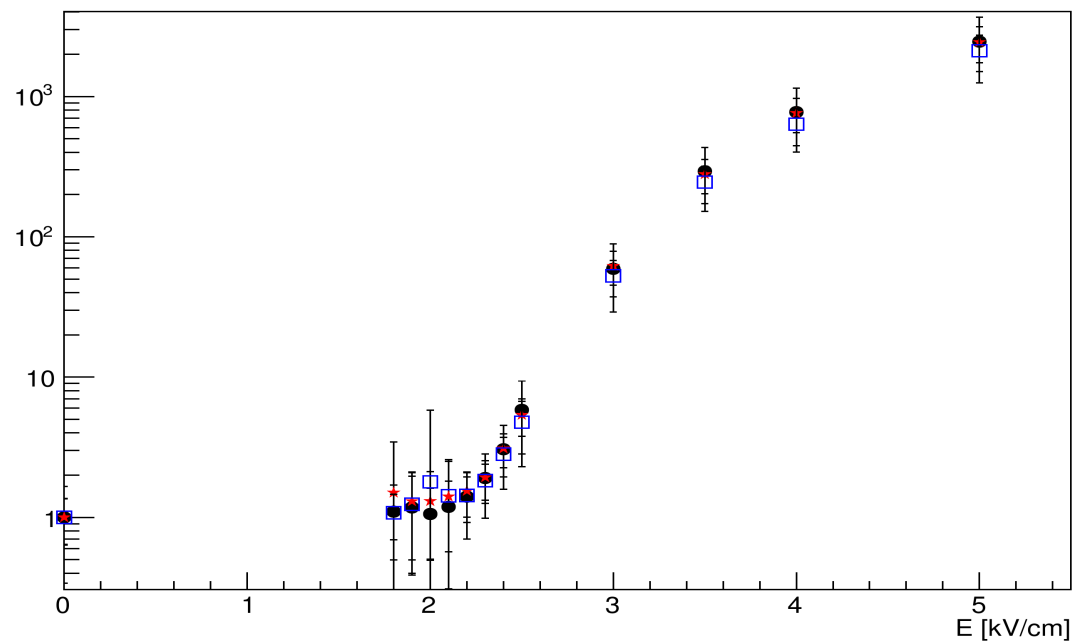
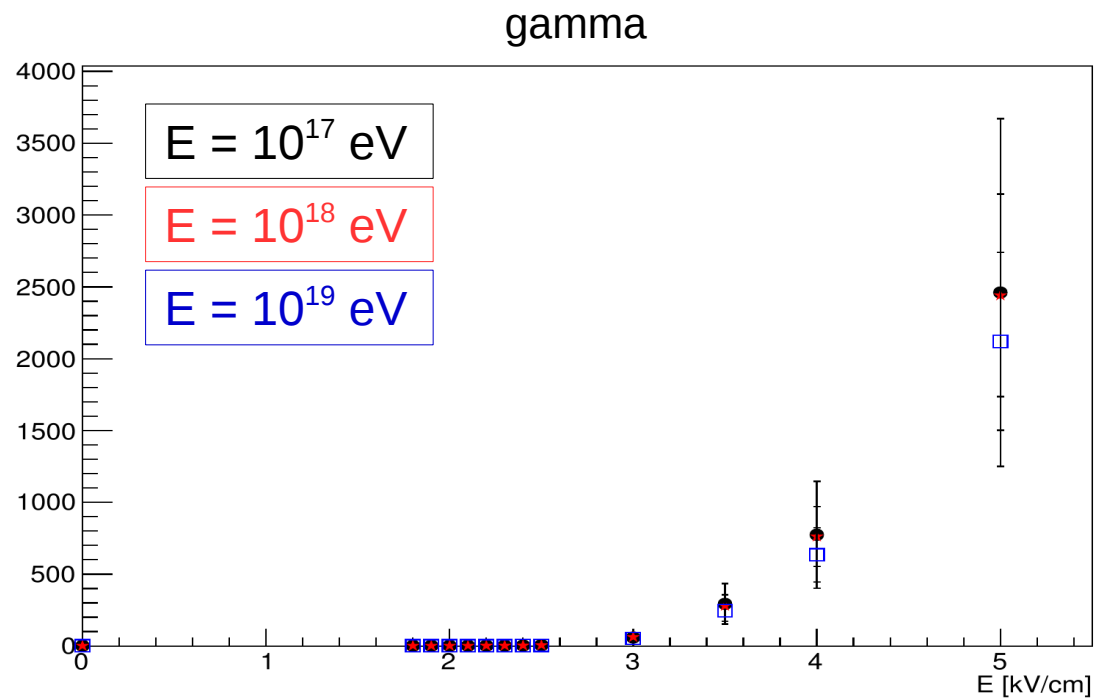


e+/e- 18

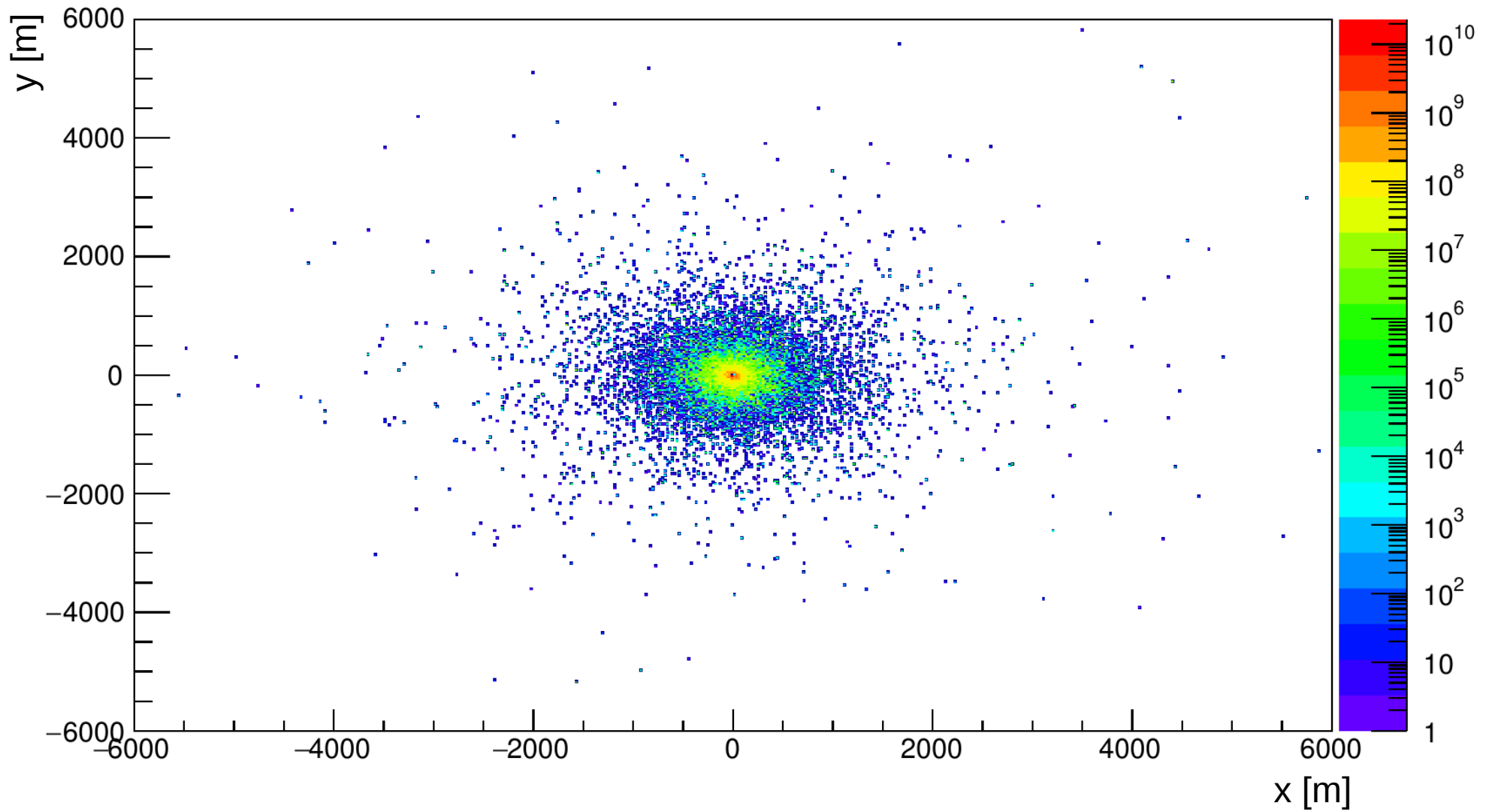


E = 10^{18} eV

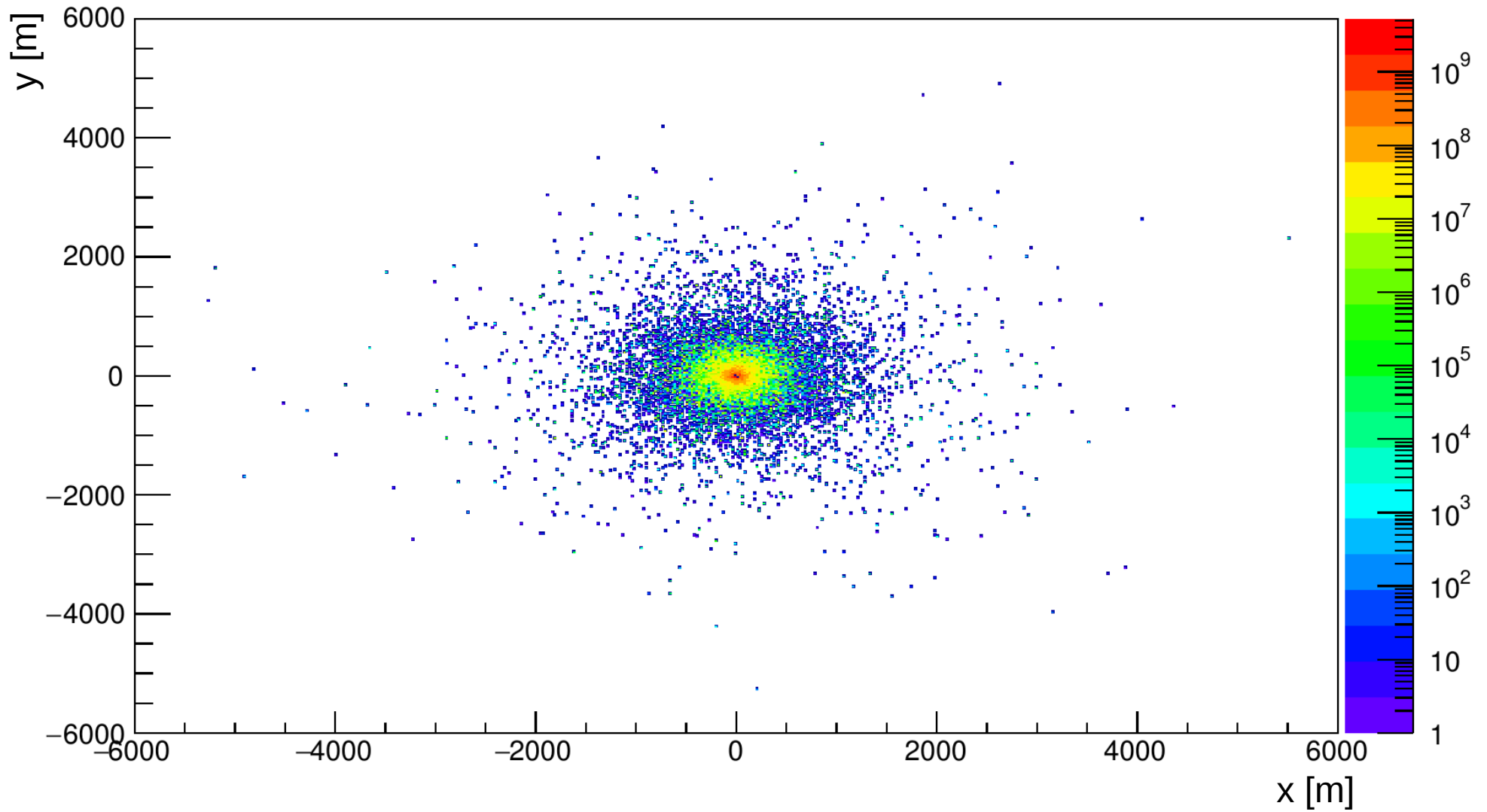
Fractional Particle Number Vs Efield



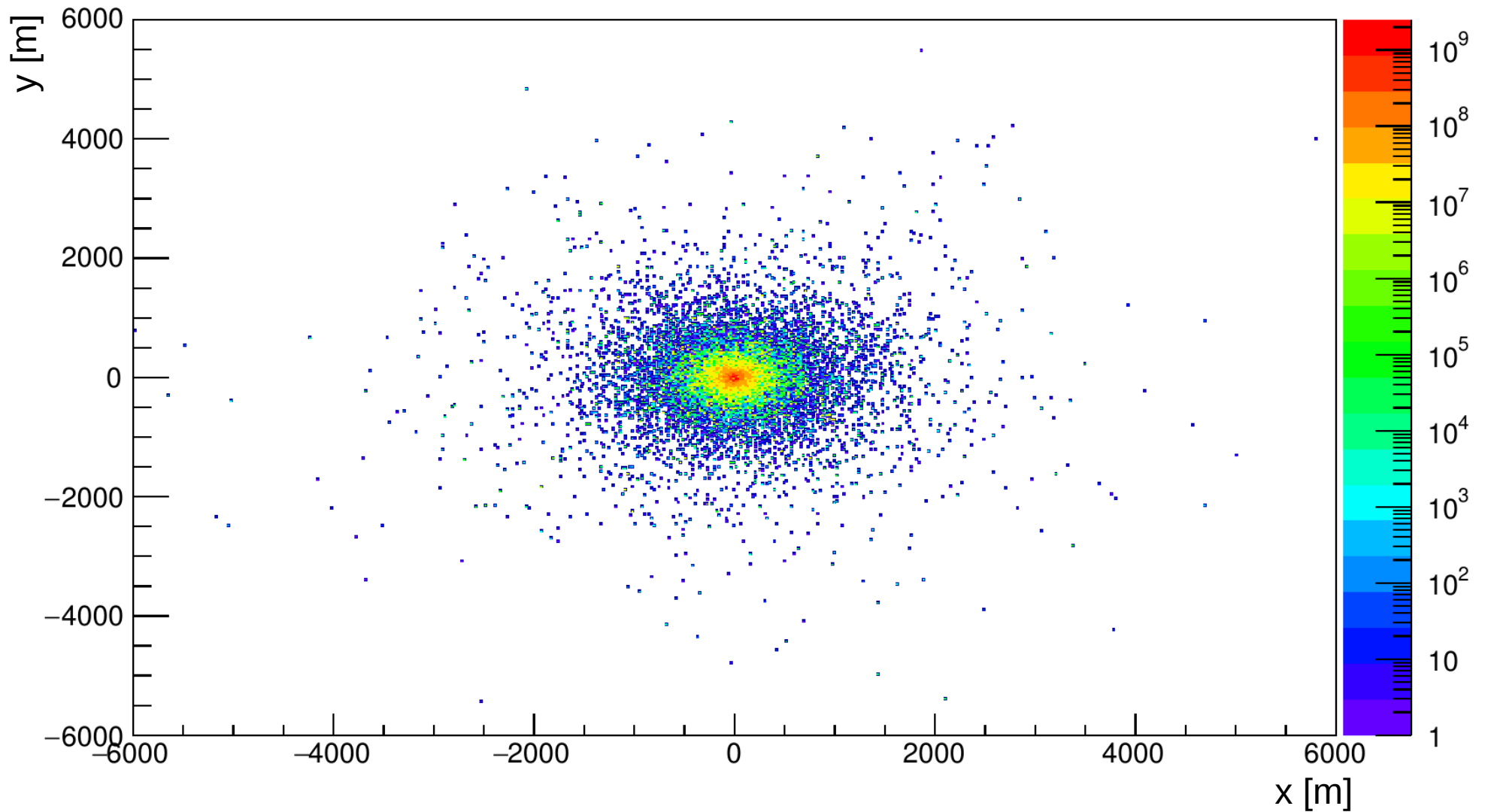
Corsika Footprint – NO field



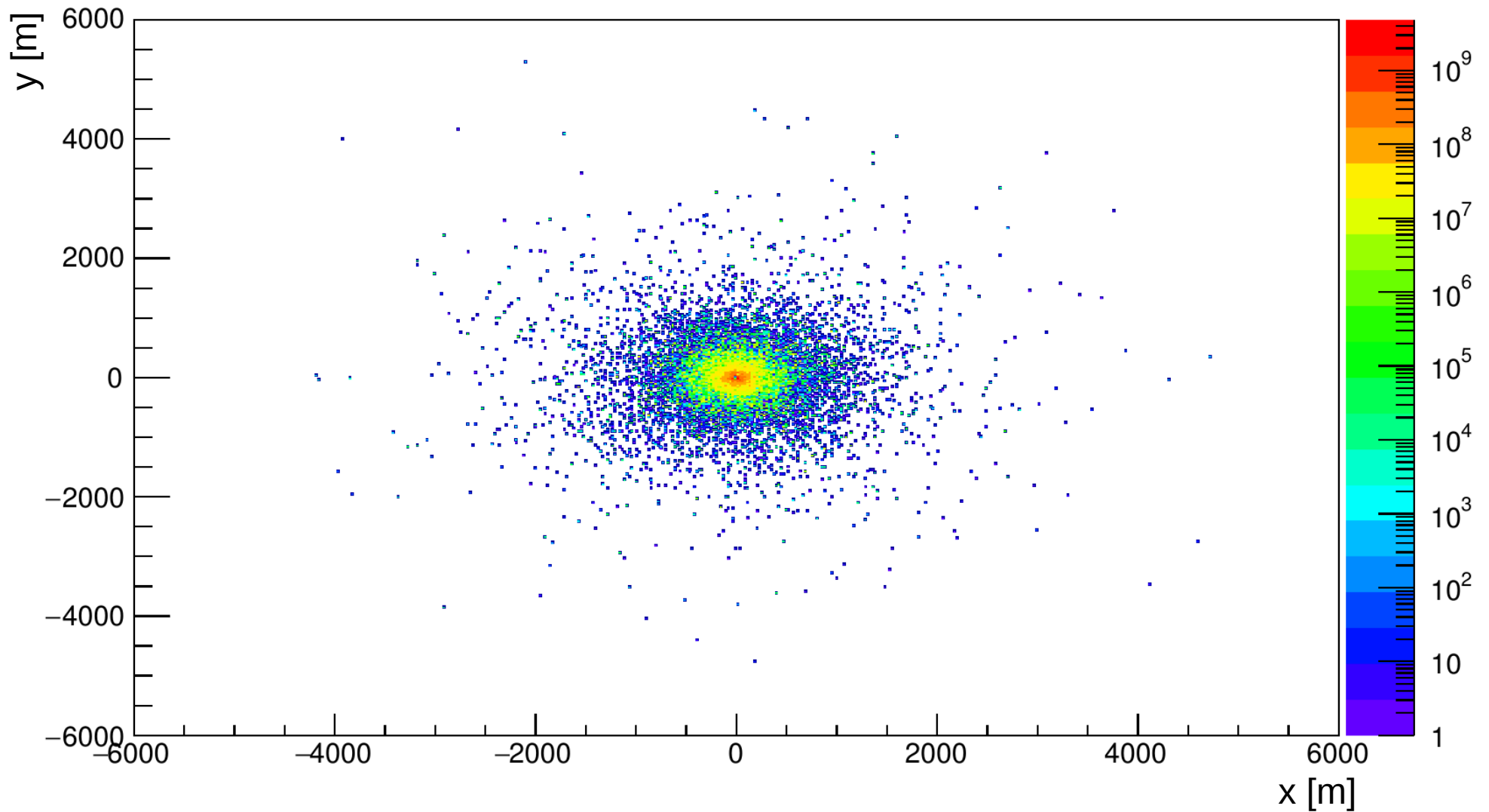
Corsika Footprint – $E_z = 1.8 \text{ kV/cm}$



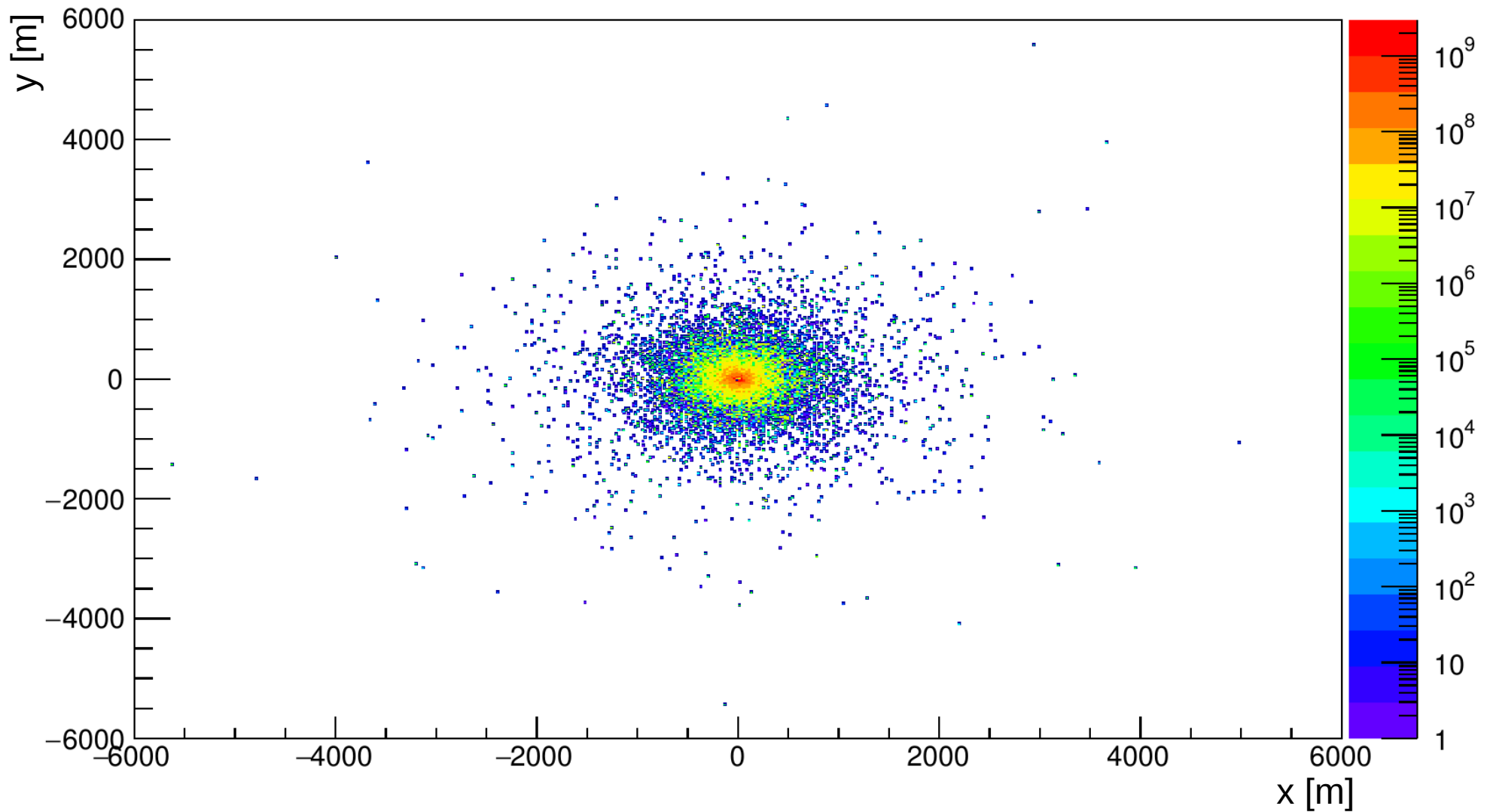
Corsika Footprint – $E_z = 1.9 \text{ kV/cm}$



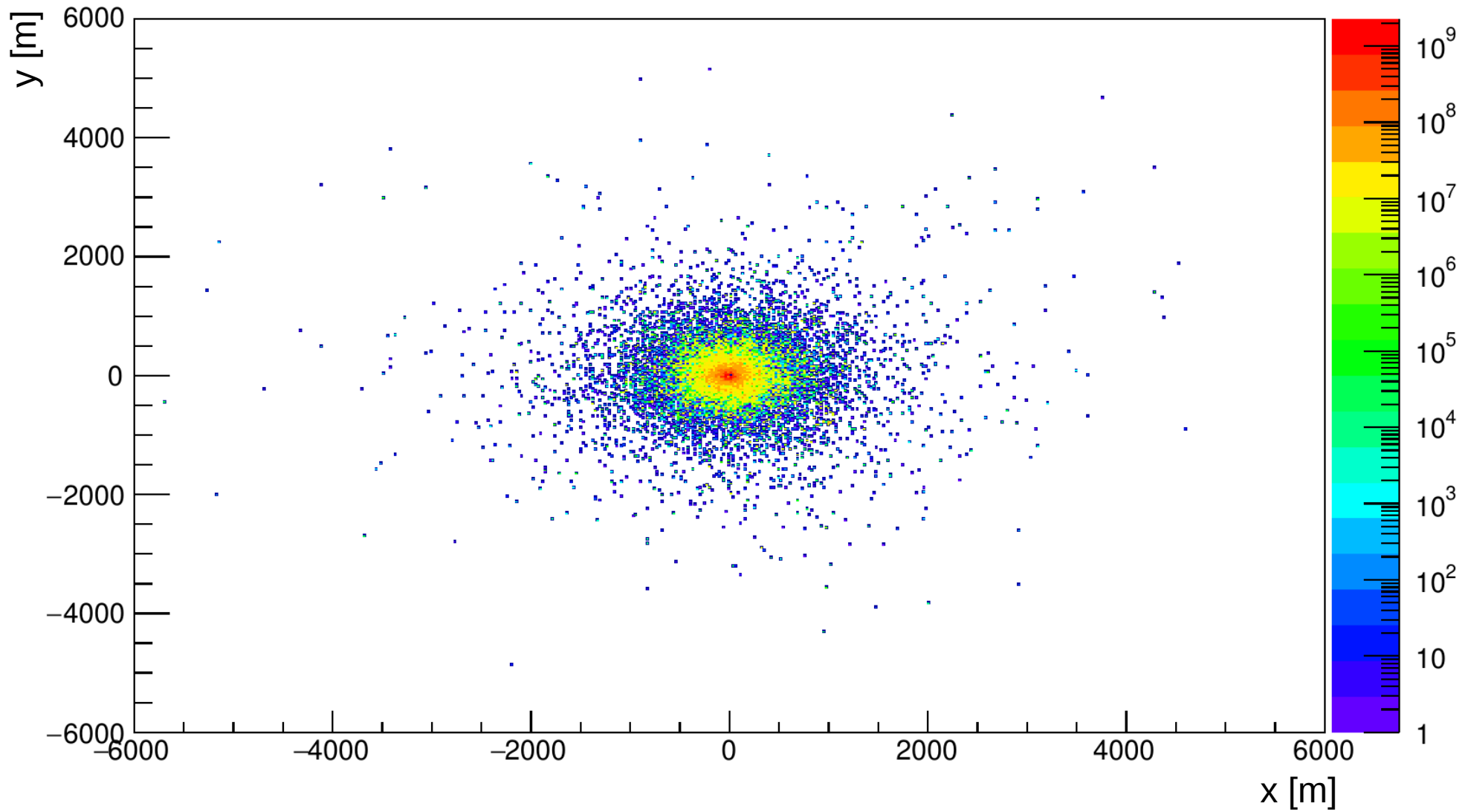
Corsika Footprint – $E_z = 2.0 \text{ kV/cm}$



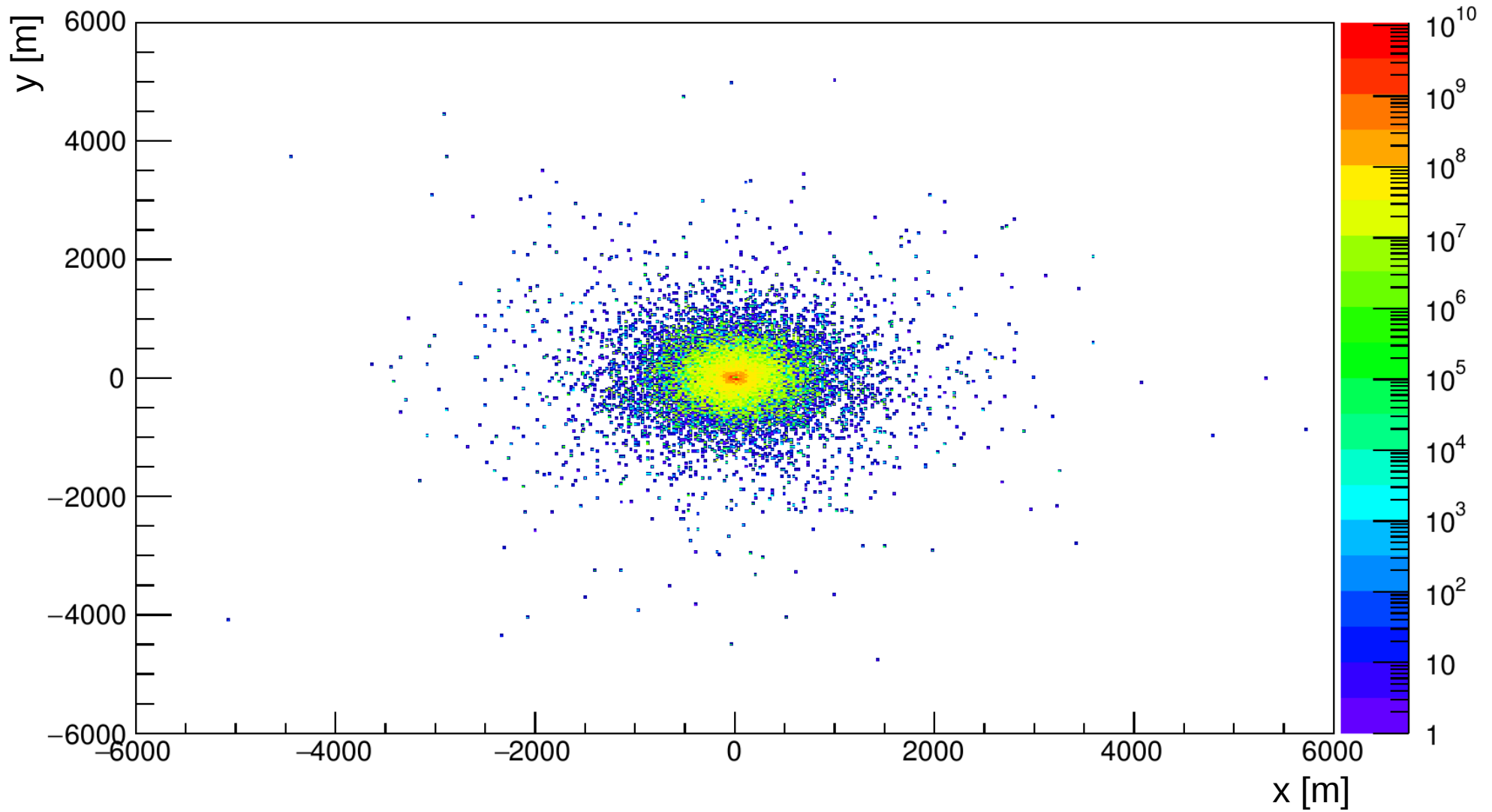
Corsika Footprint – $E_z = 2.1 \text{ kV/cm}$



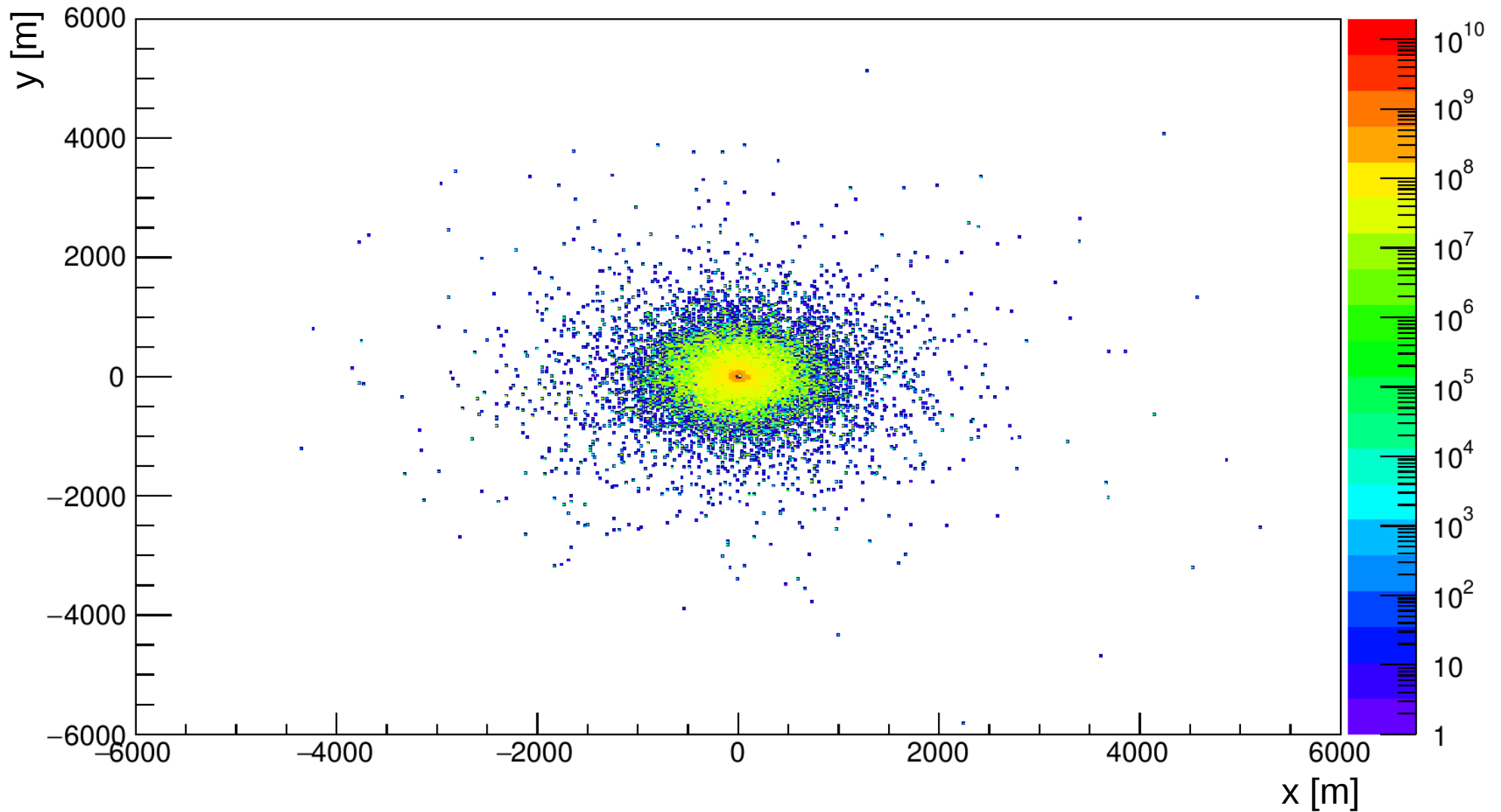
Corsika Footprint – $E_z = 2.2 \text{ kV/cm}$



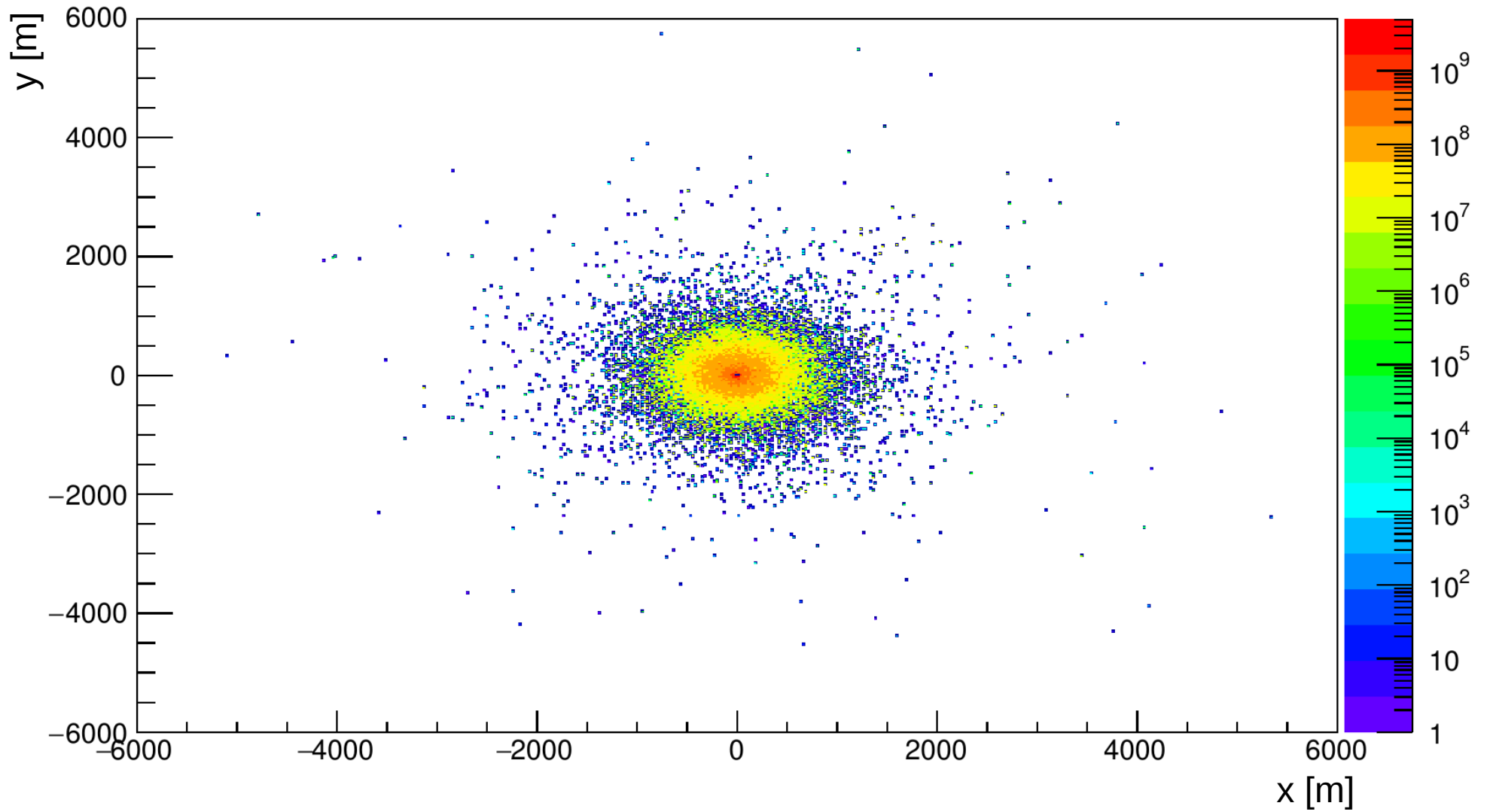
Corsika Footprint – $E_z = 2.3 \text{ kV/cm}$



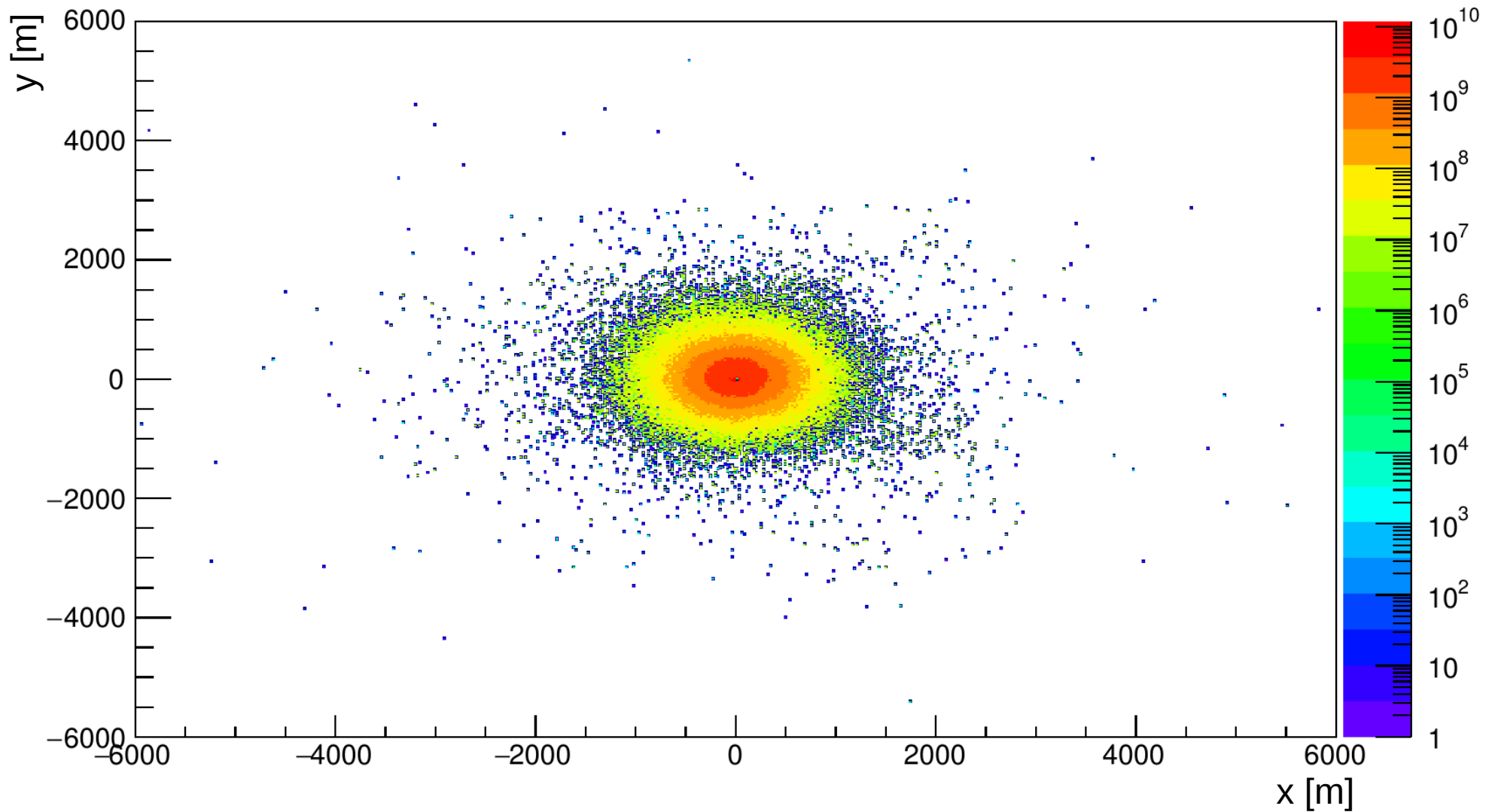
Corsika Footprint – $E_z = 2.4 \text{ kV/cm}$



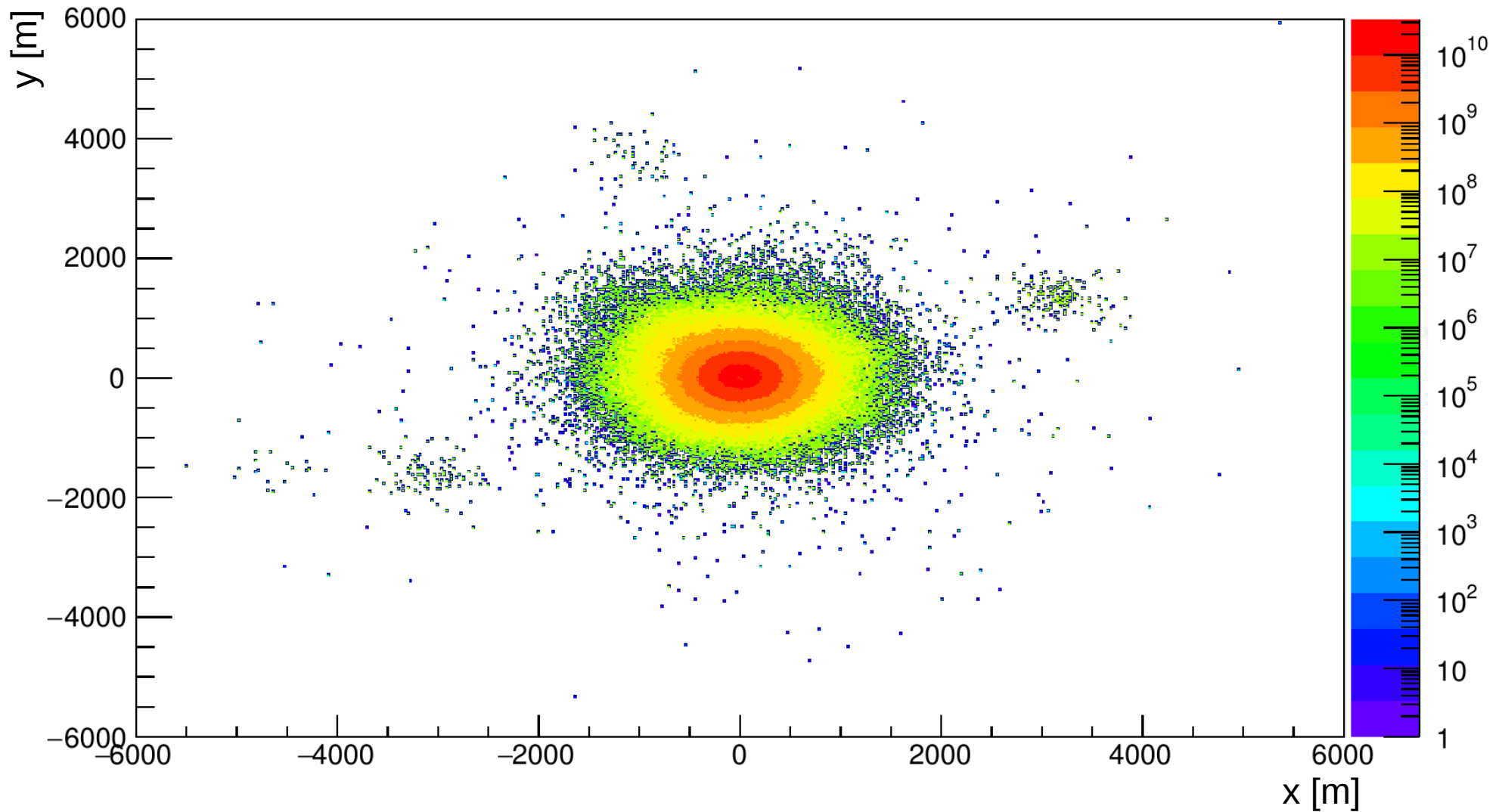
Corsika Footprint – $E_z = 2.5 \text{ kV/cm}$



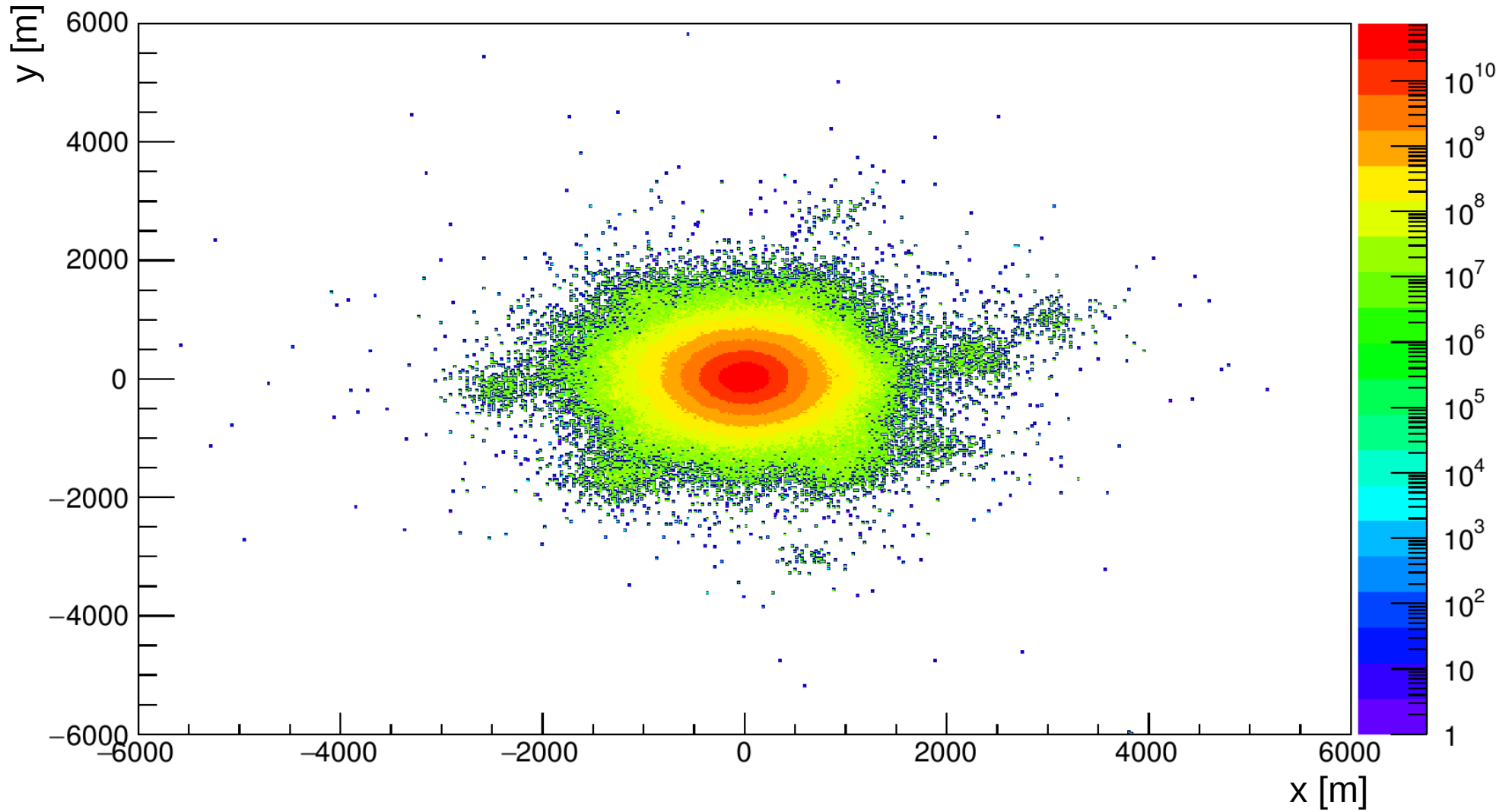
Corsika Footprint – $E_z = 3.0 \text{ kV/cm}$



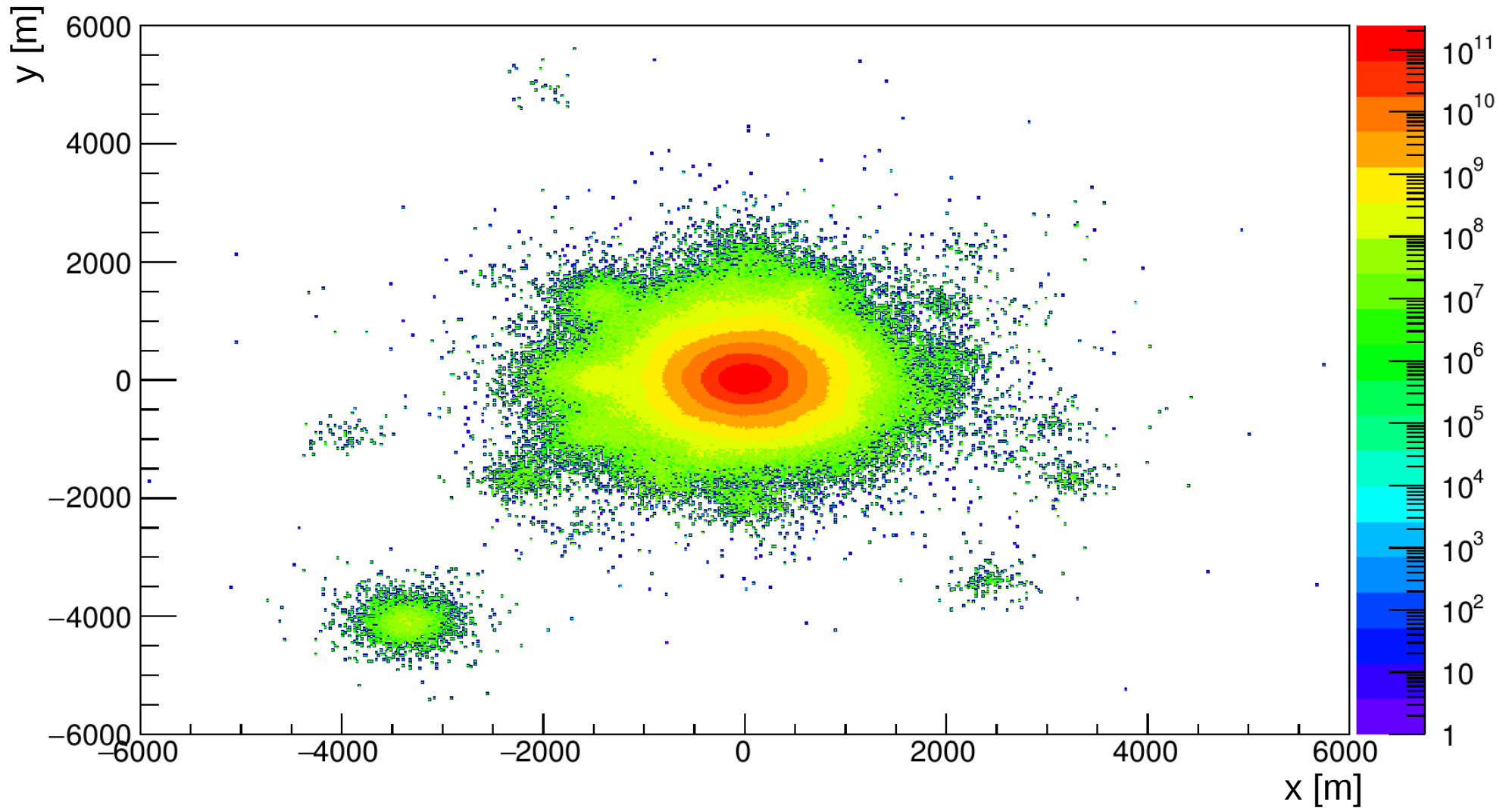
Corsika Footprint – $E_z = 3.5 \text{ kV/cm}$



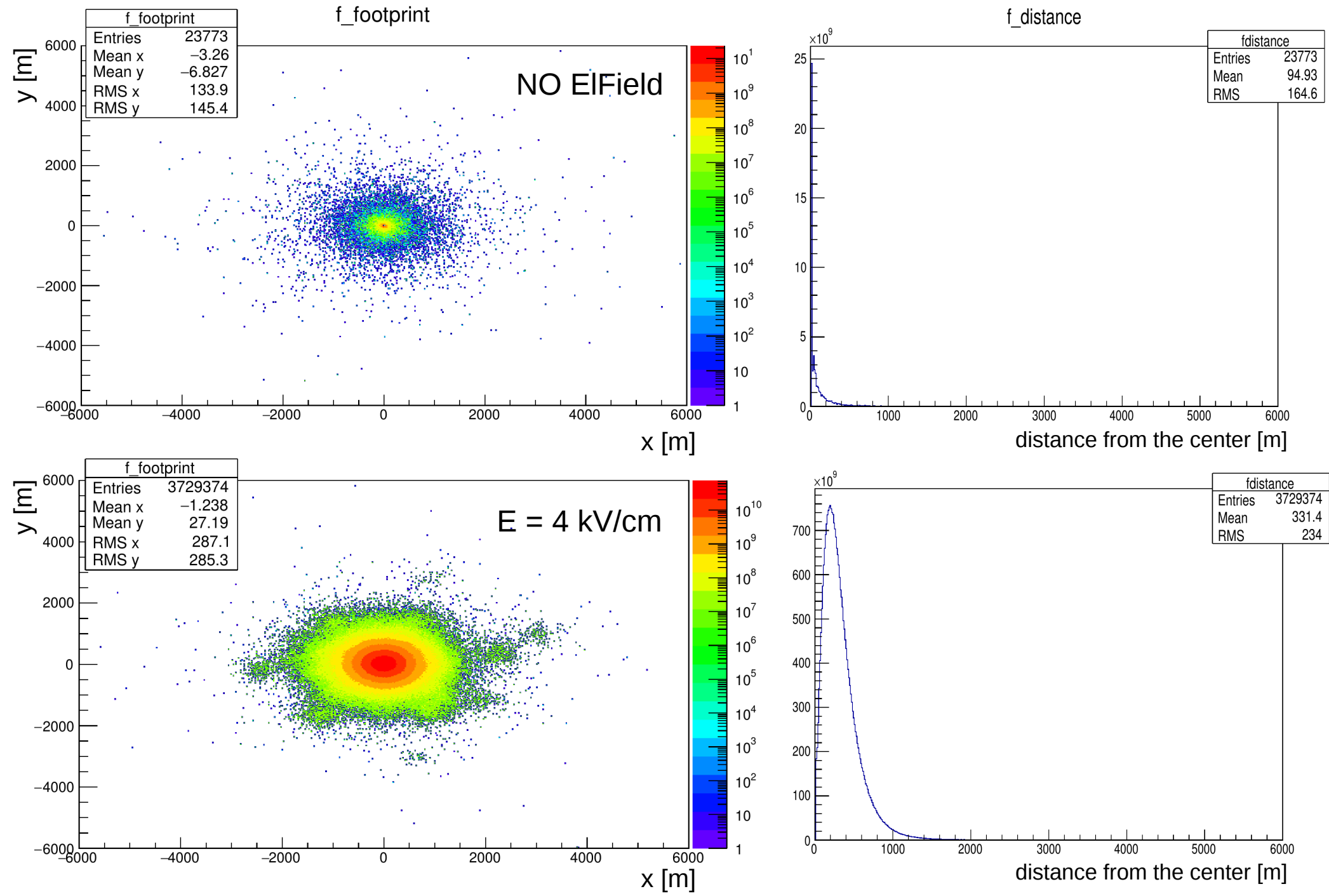
Corsika Footprint – $E_z = 4.0$ kV/cm



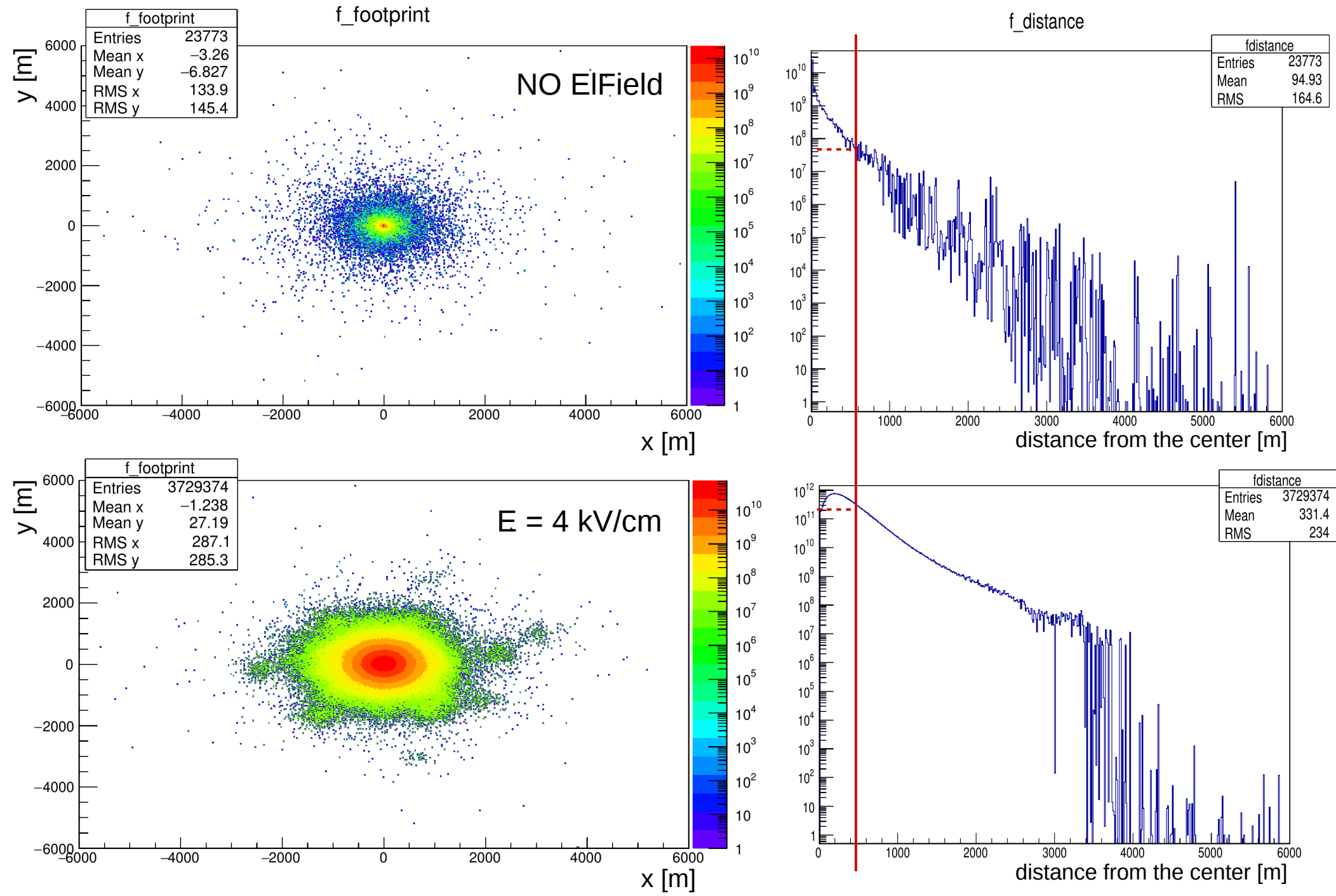
Corsika Footprint – $E_z = 5.0$ kV/cm



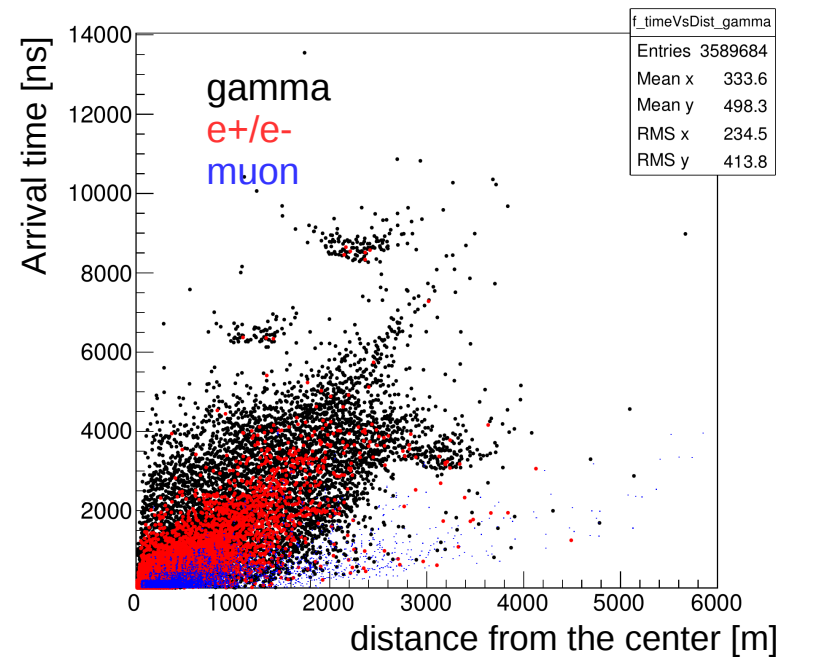
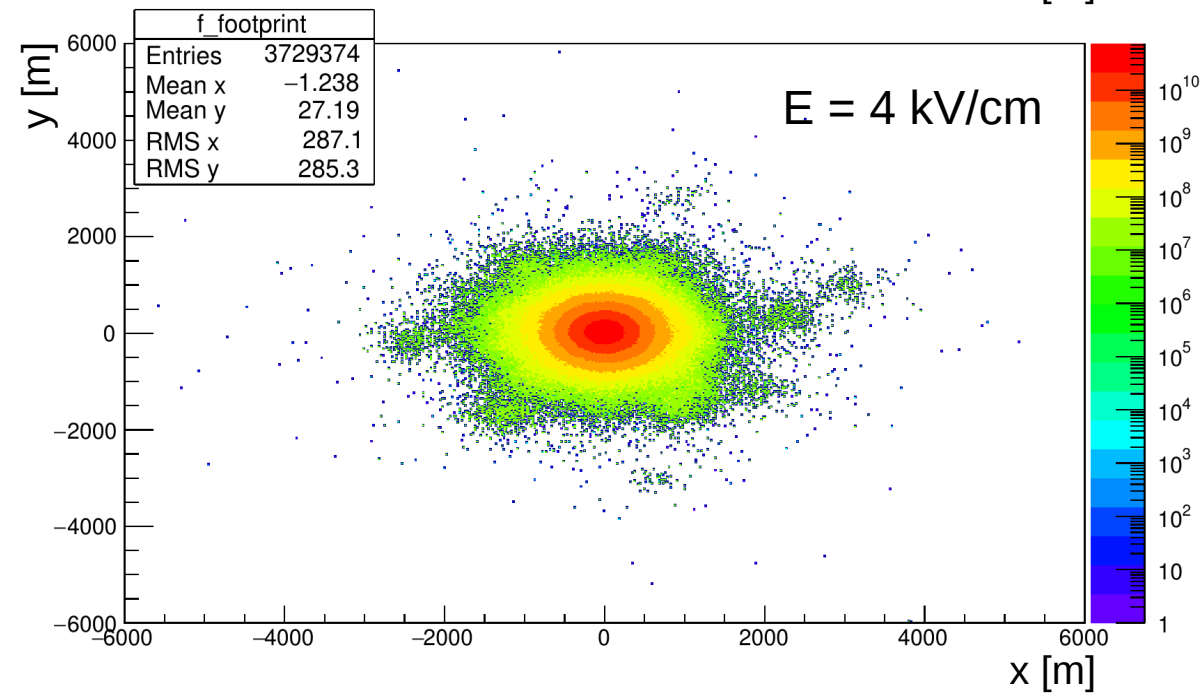
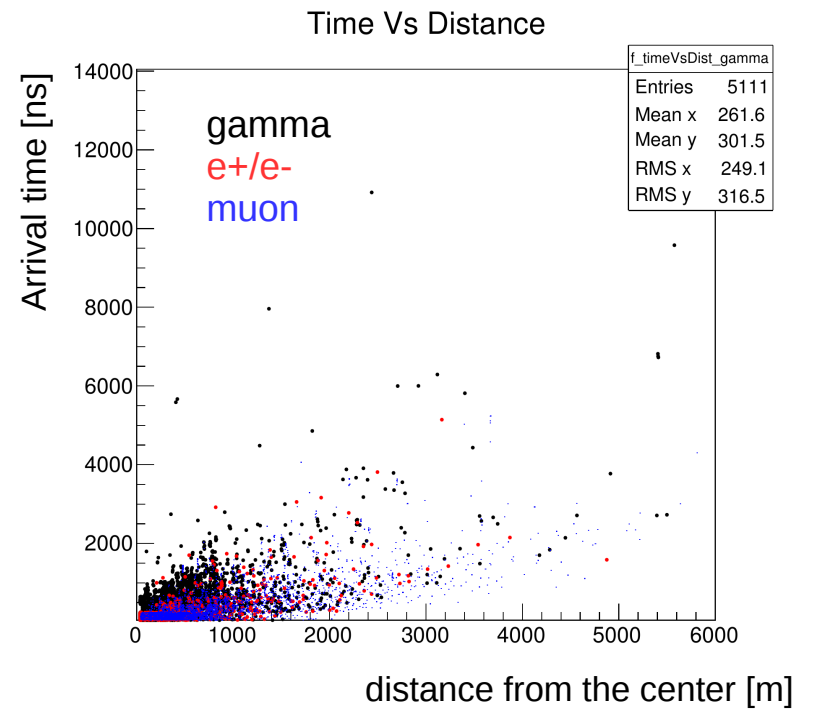
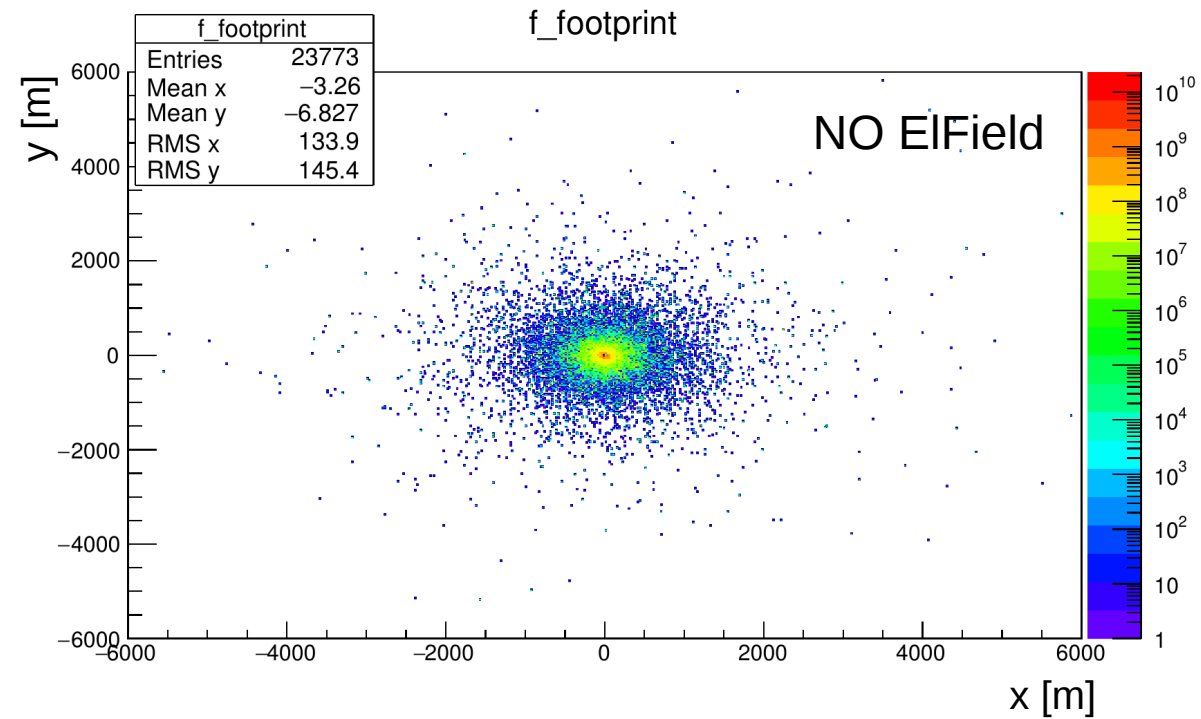
Corsika Footprint – First Example



Corsika Footprint – First Example

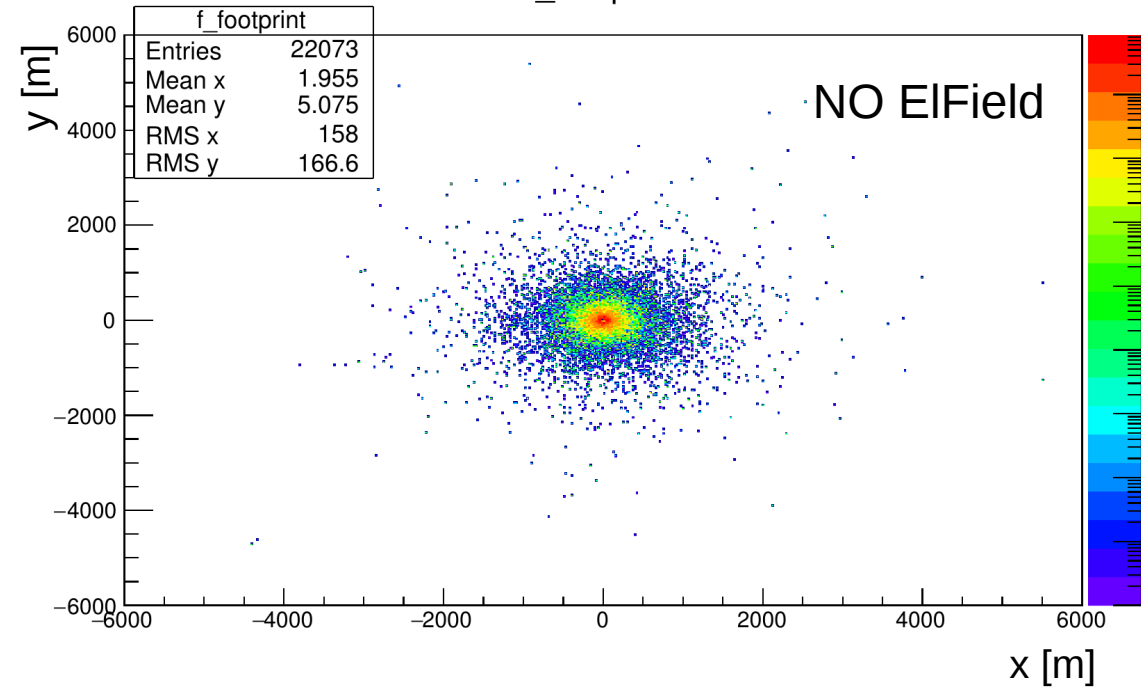


Corsika Footprint – First Example

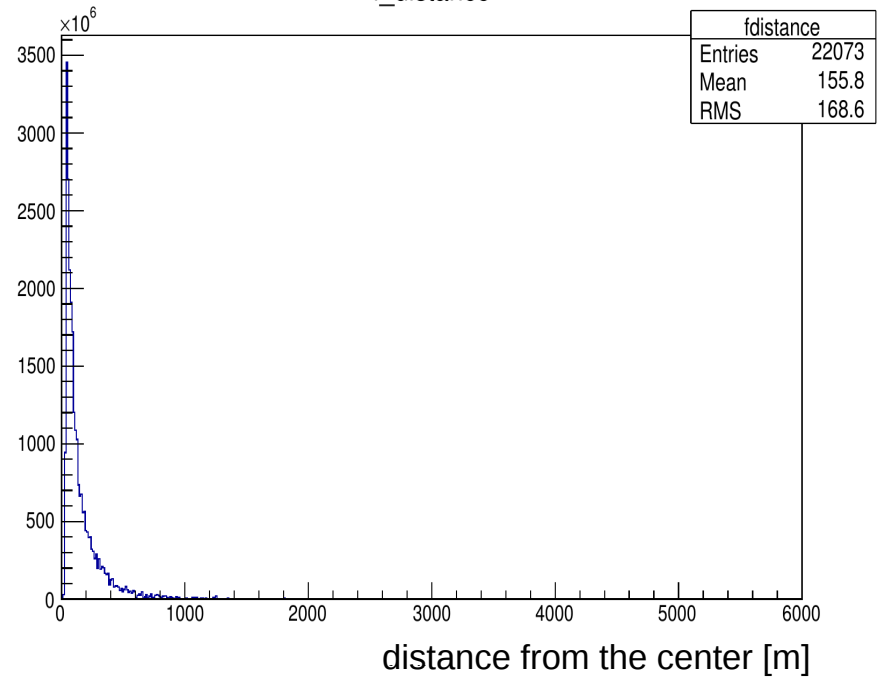


Corsika Footprint – Second Example

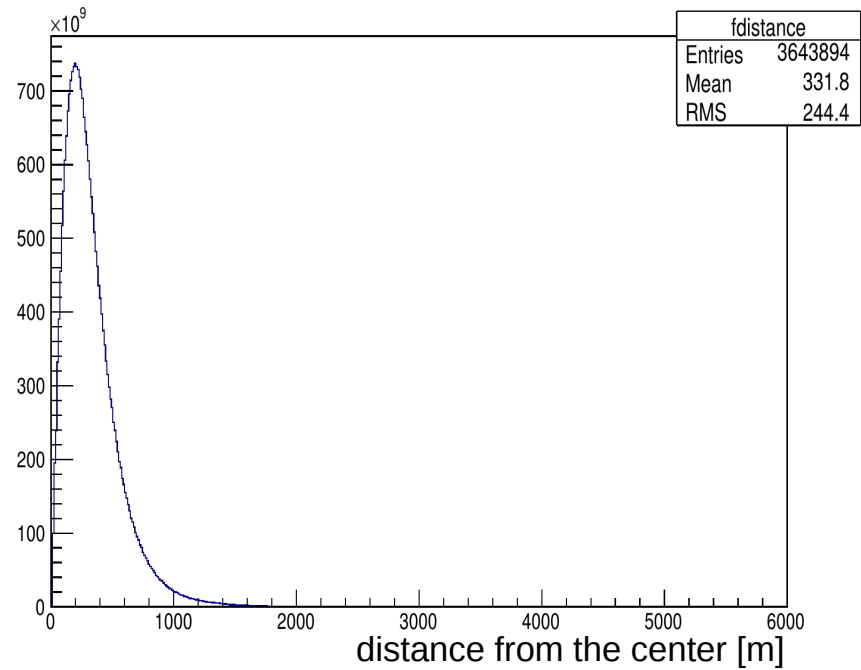
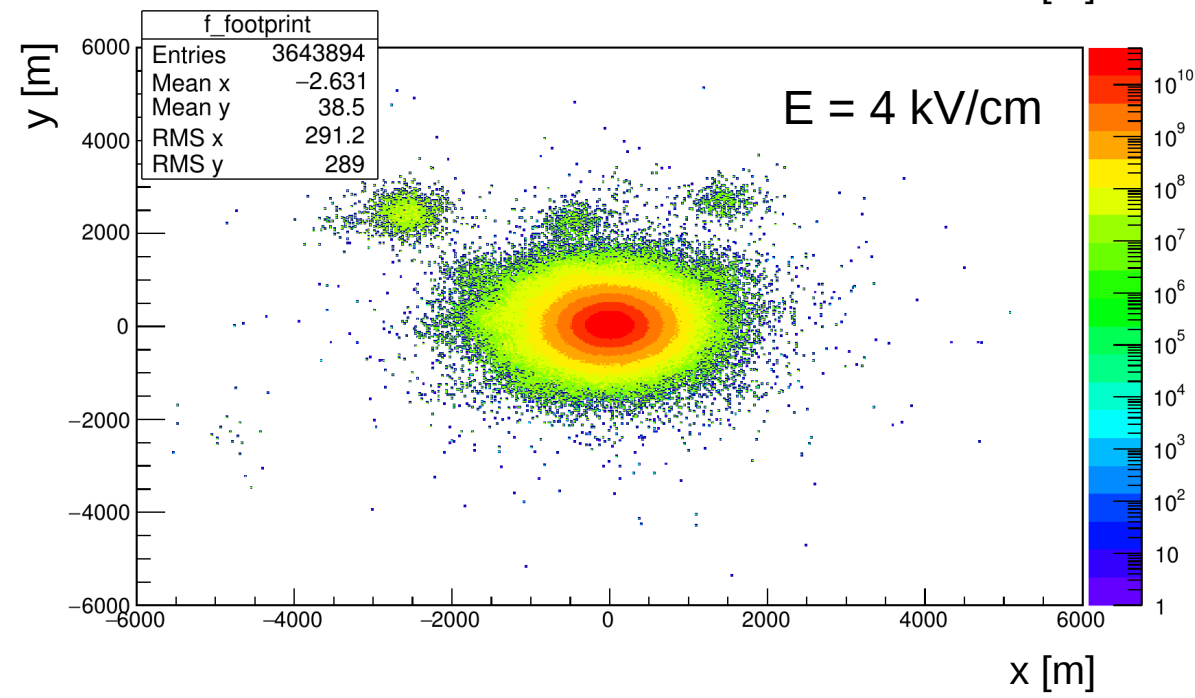
f_footprint



f_distance

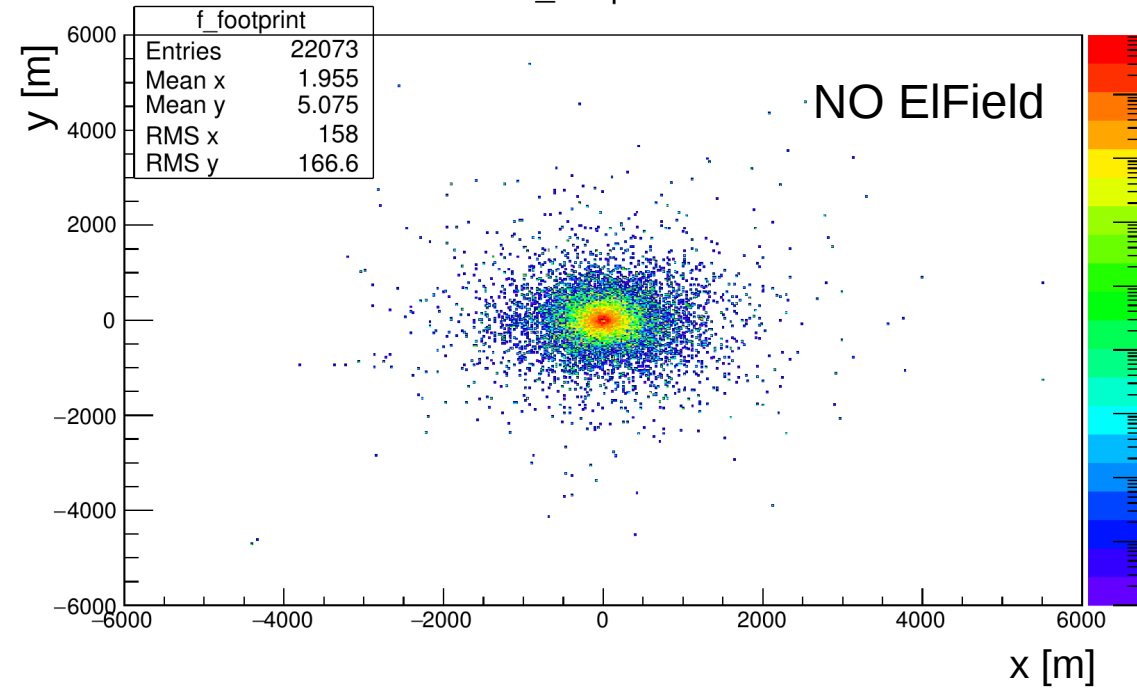


E = 4 kV/cm

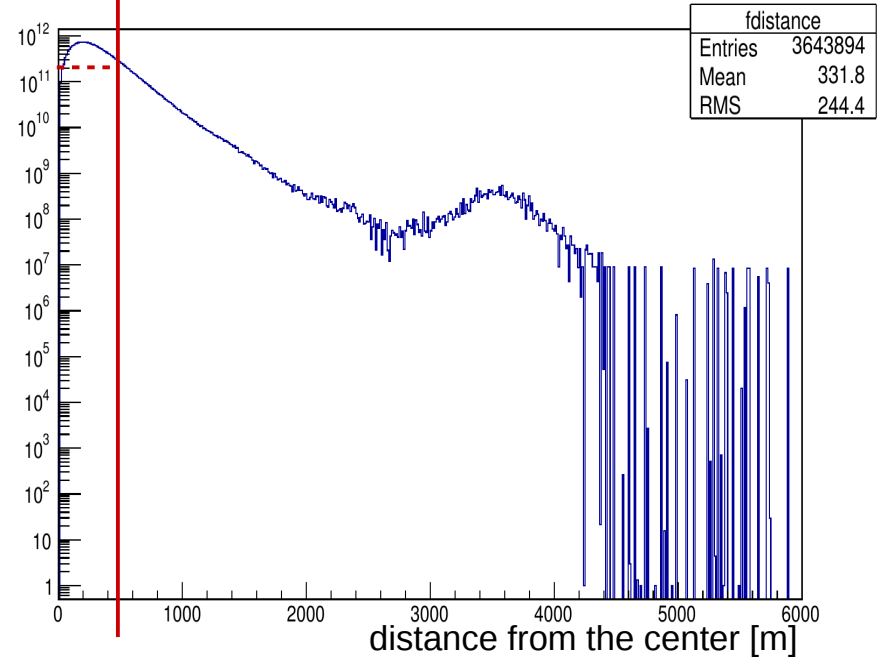
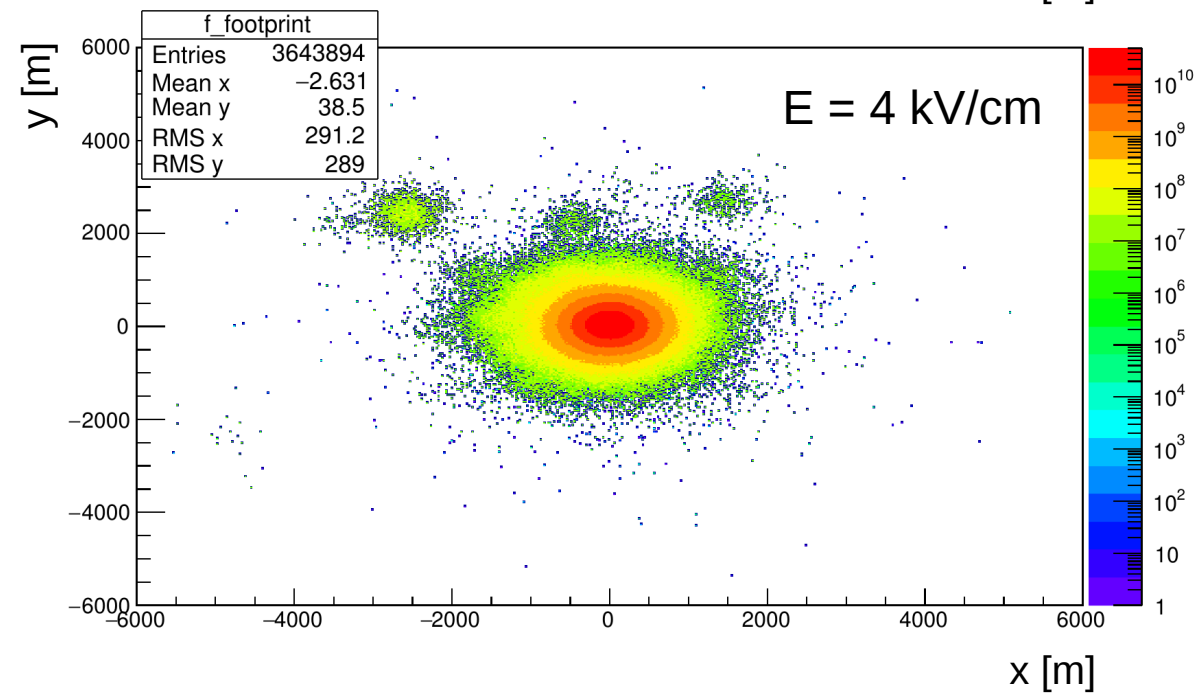
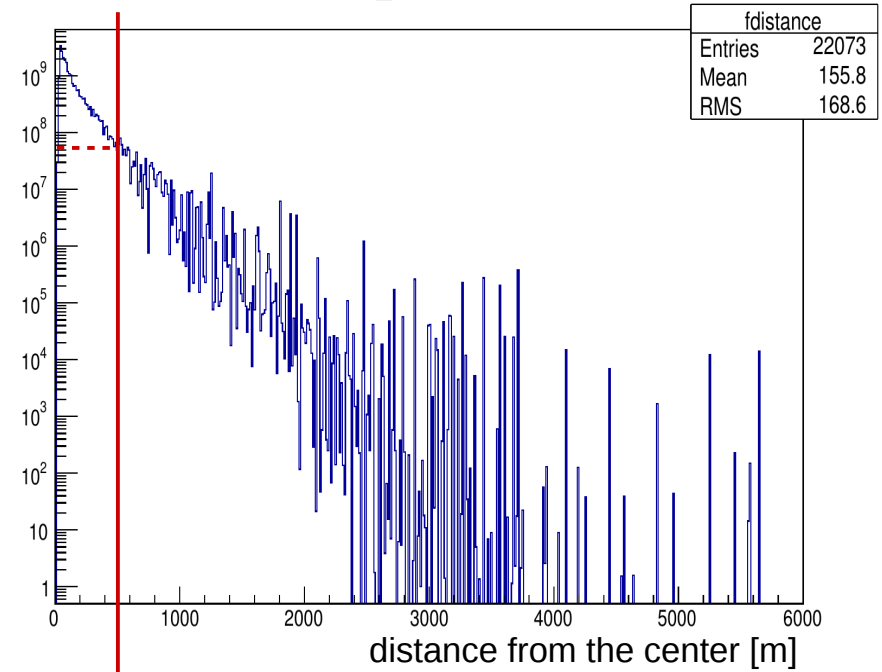


Corsika Footprint – Second Example

f_footprint

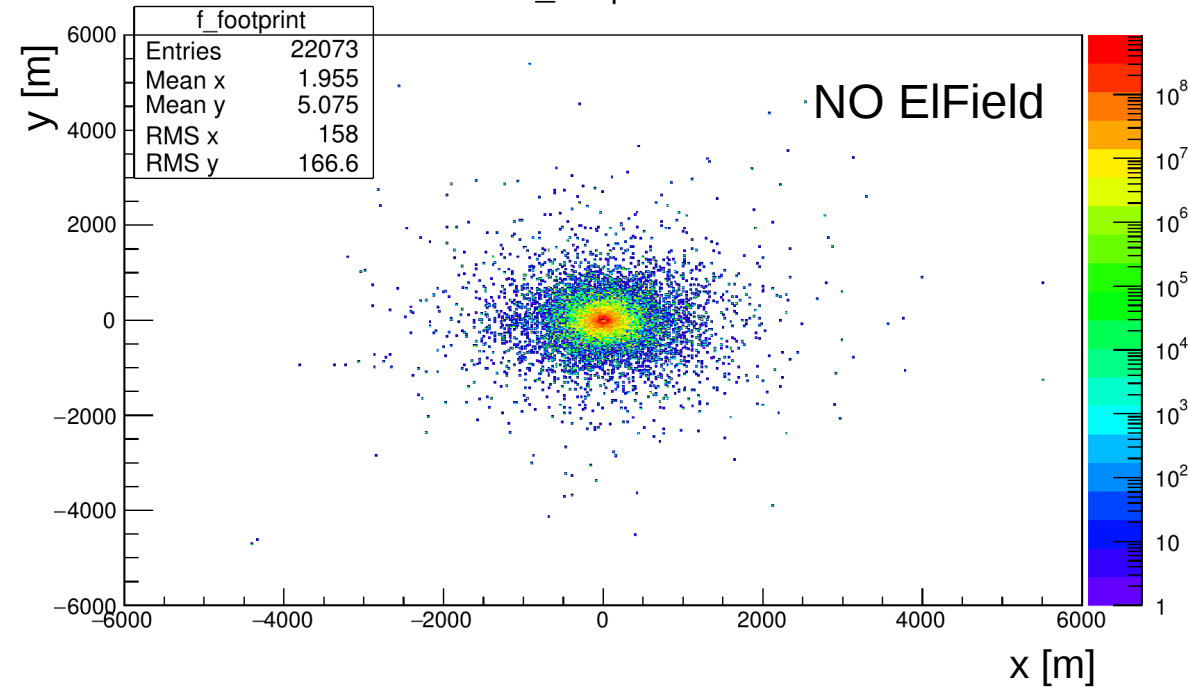


f_distance

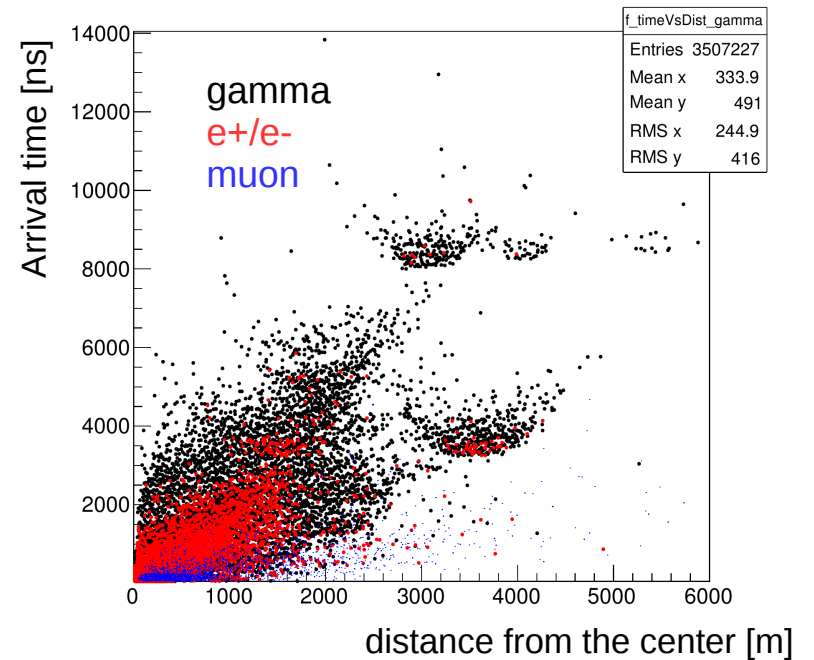
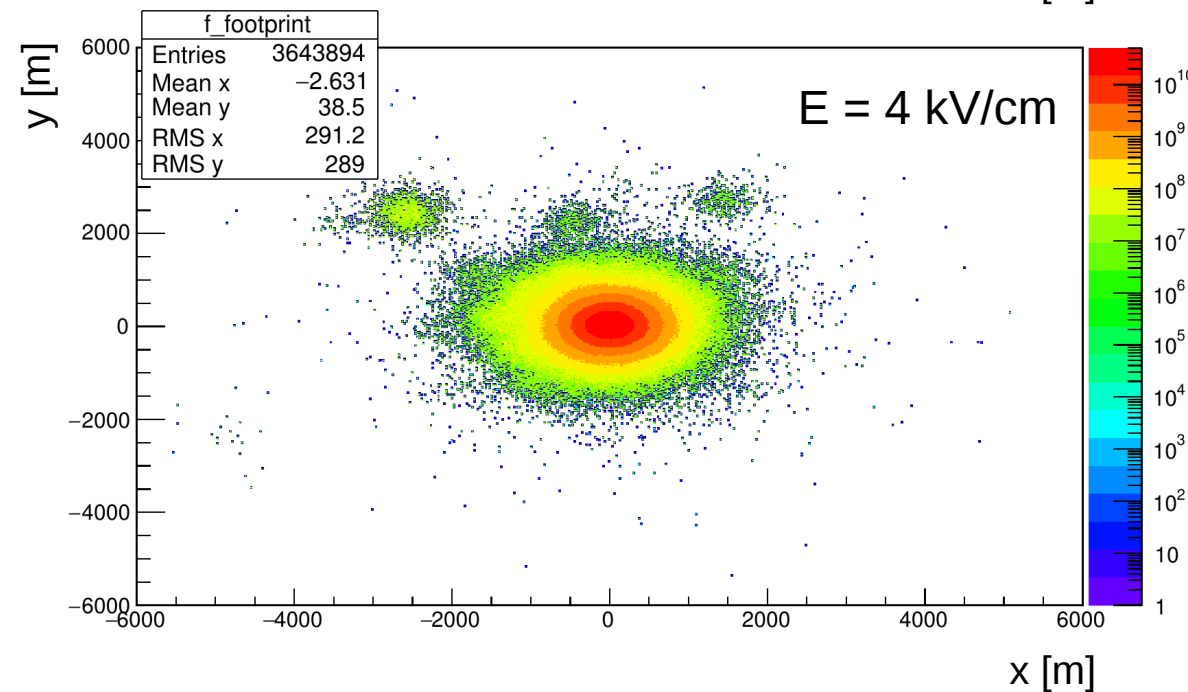
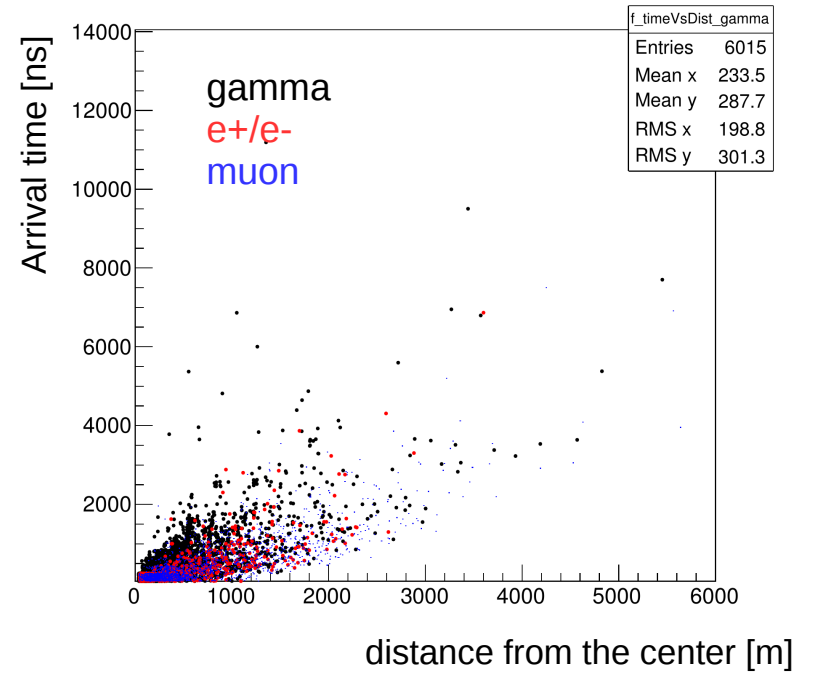


Corsika Footprint – Second Example

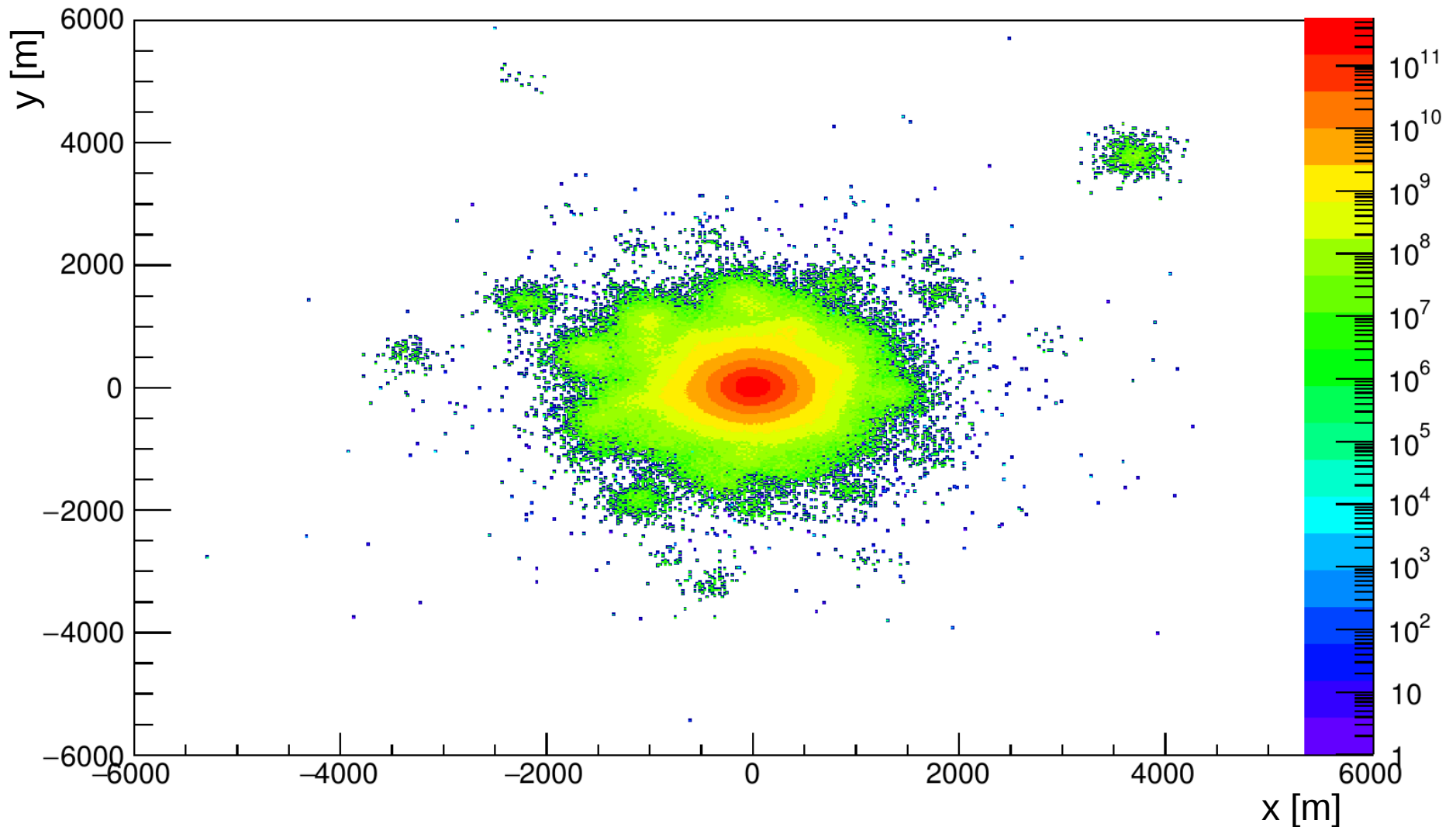
f_footprint



Time Vs Distance

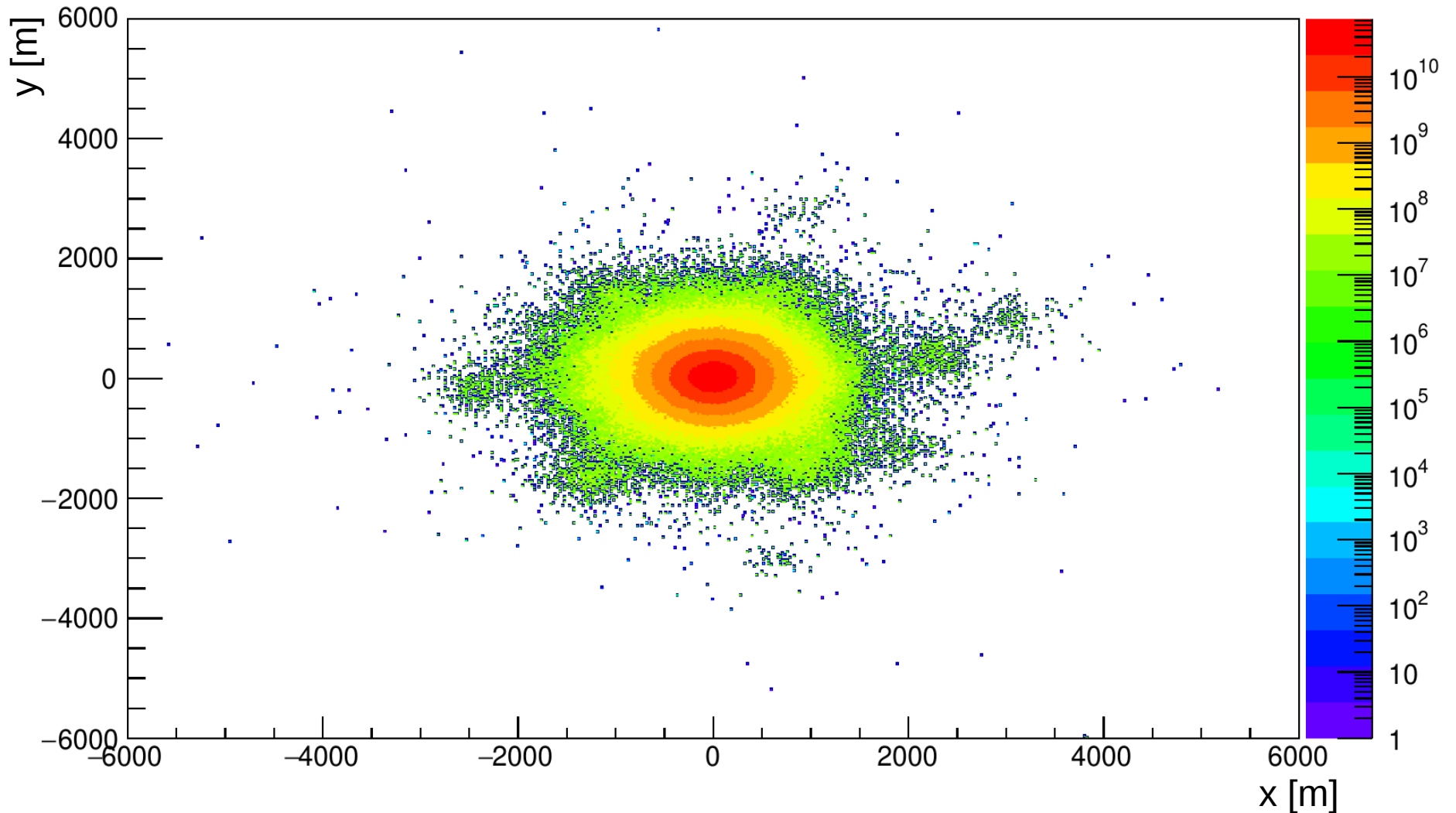


Particle Number Vs Cloud Altitude - Footprint Cloud base: 0.5 km



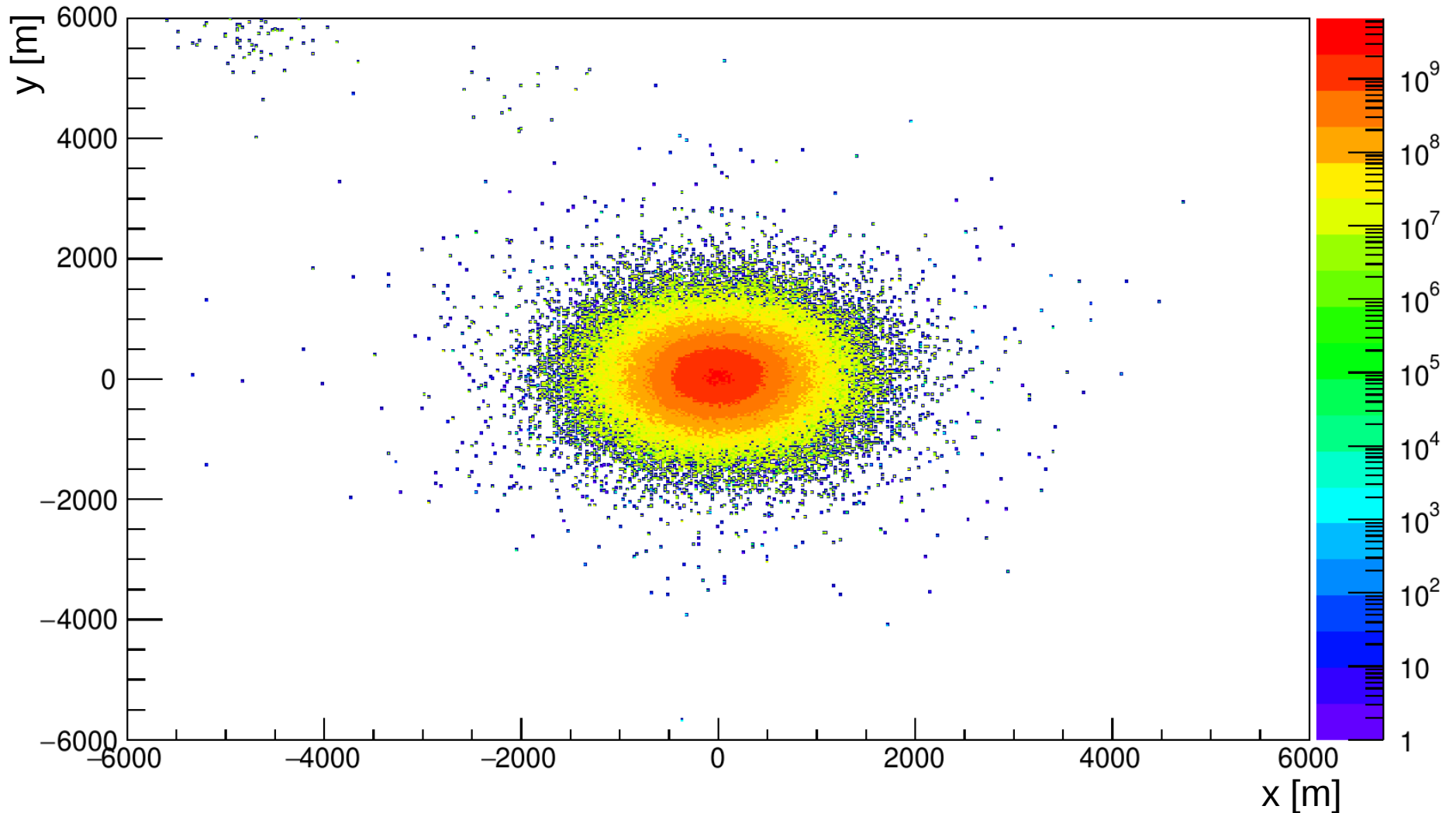
Particle Number Vs Altitude - Footprint

Cloud base: 1.0 km



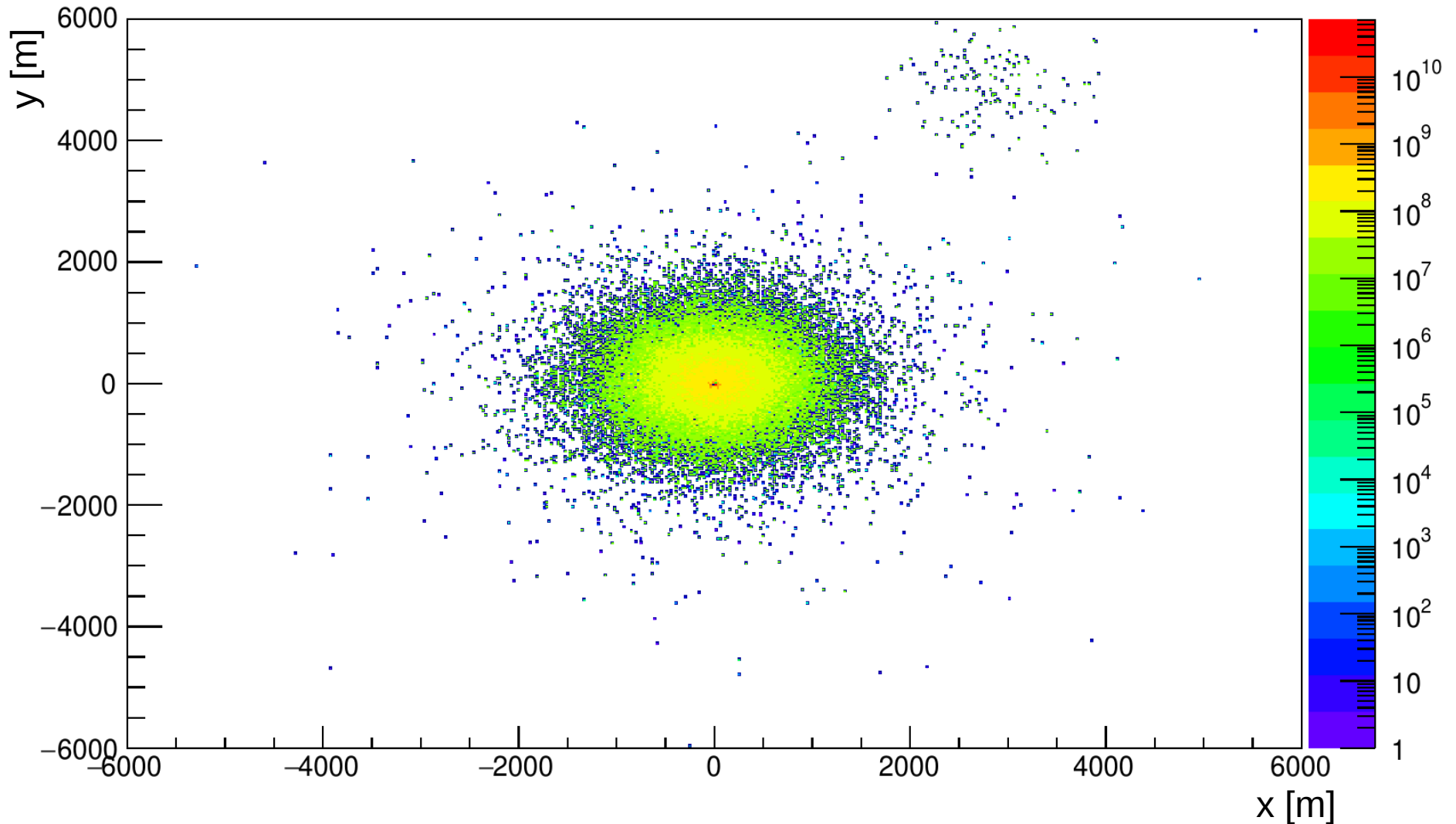
Particle Number Vs Altitude - Footprint

Cloud base: 2.0 km



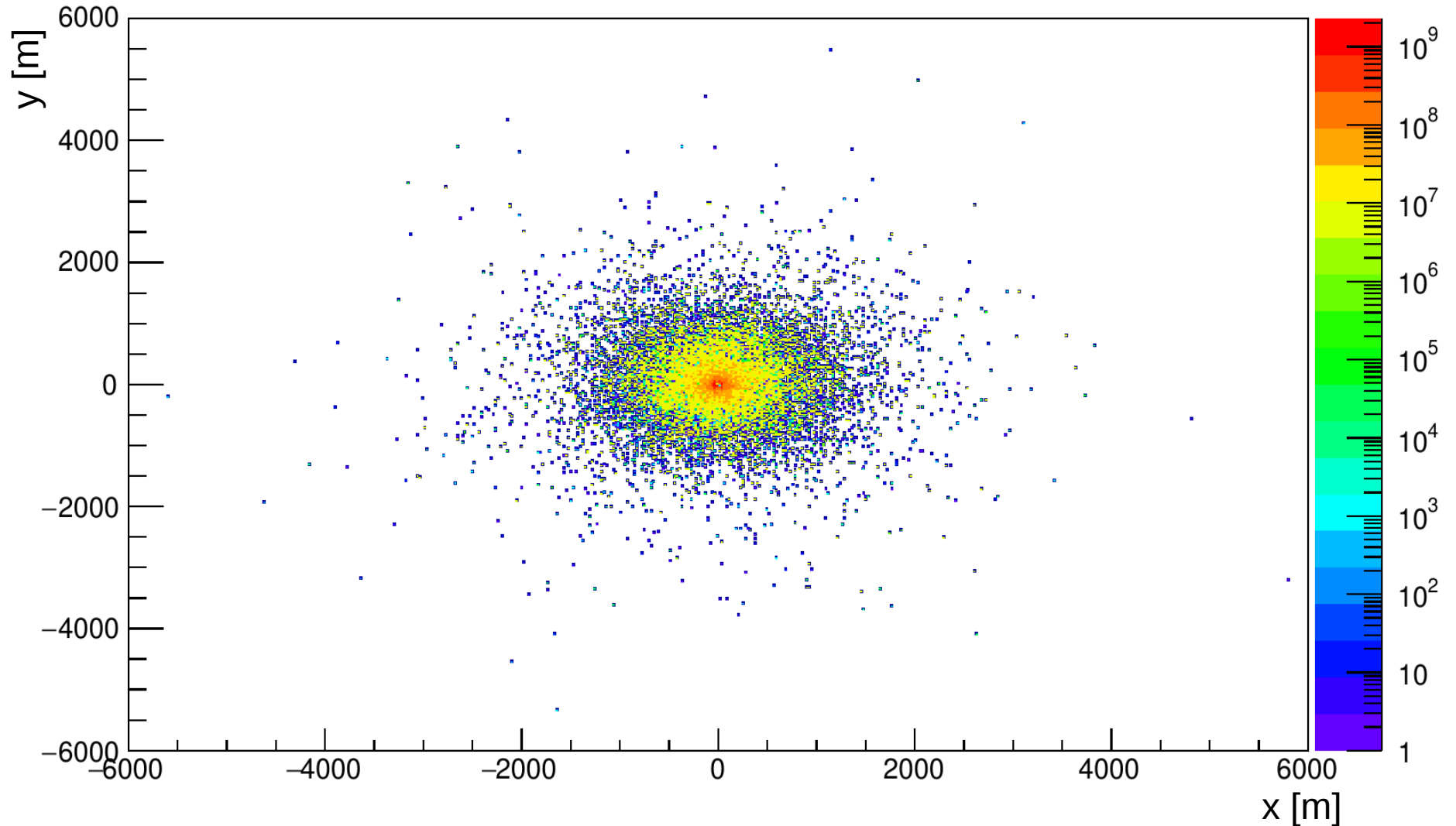
Particle Number Vs Altitude - Footprint

Cloud base: 3.0 km



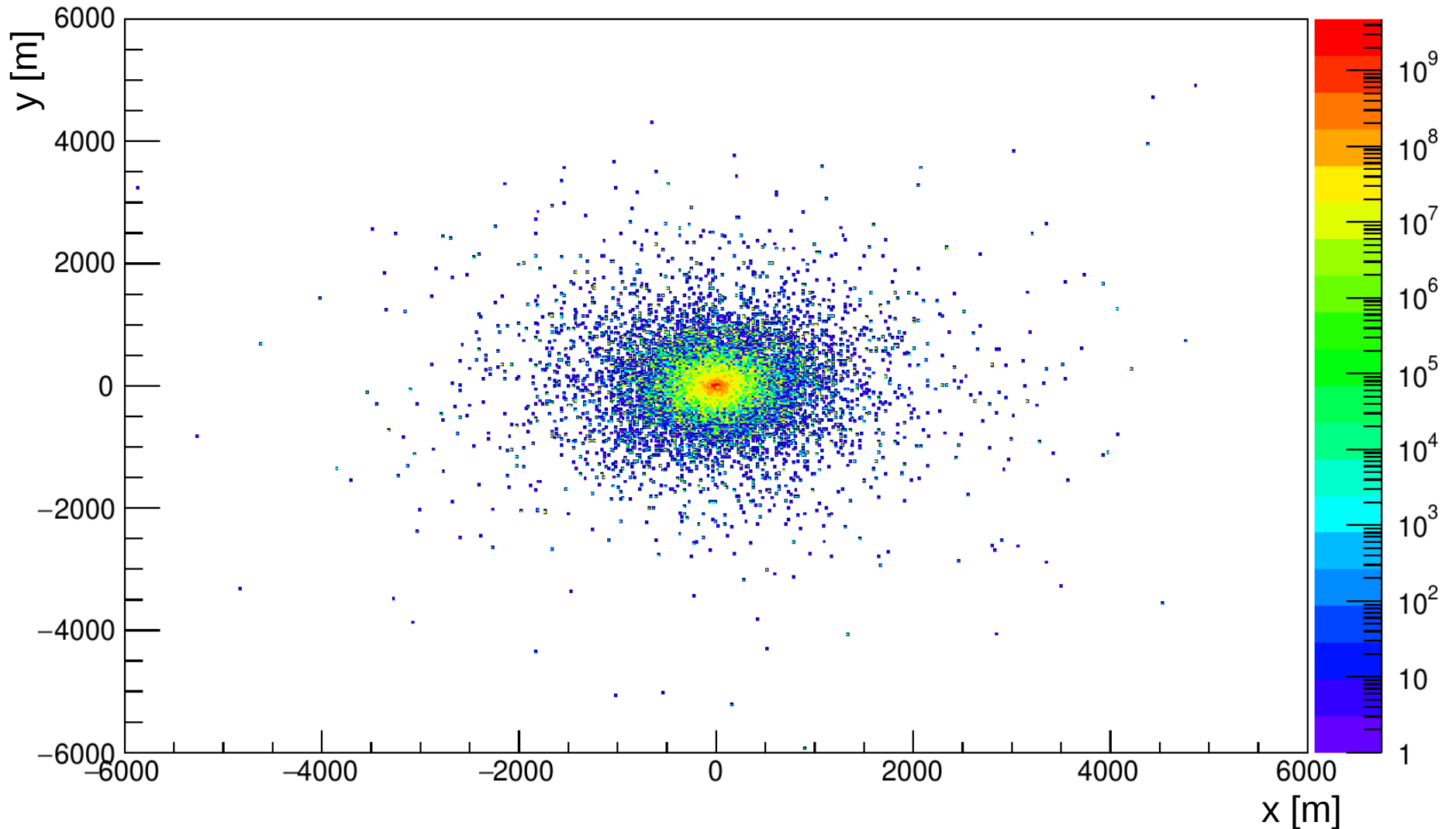
Particle Number Vs Altitude - Footprint

Cloud base: 4.0 km



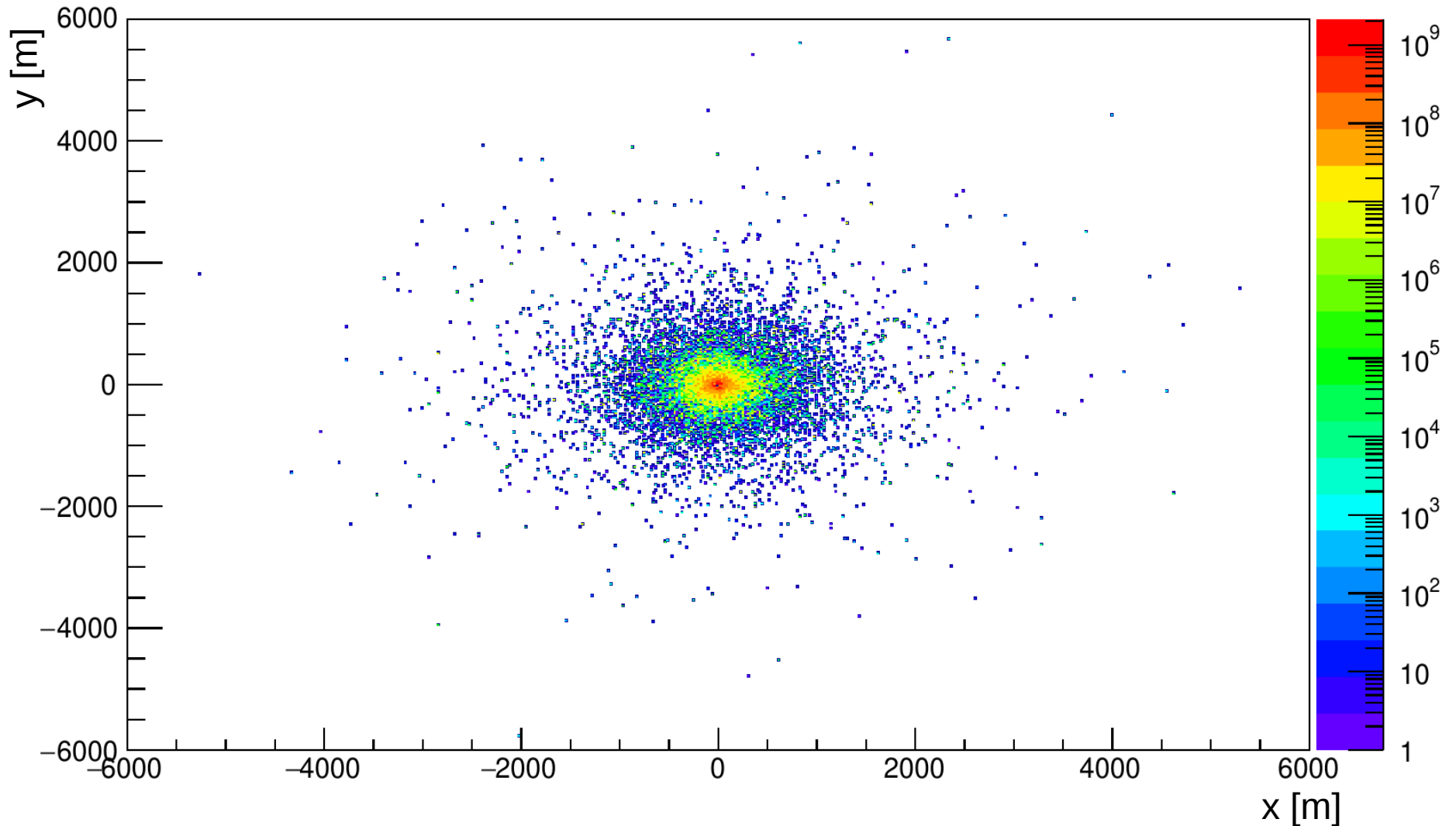
Particle Number Vs Altitude - Footprint

Cloud base: 5.0 km

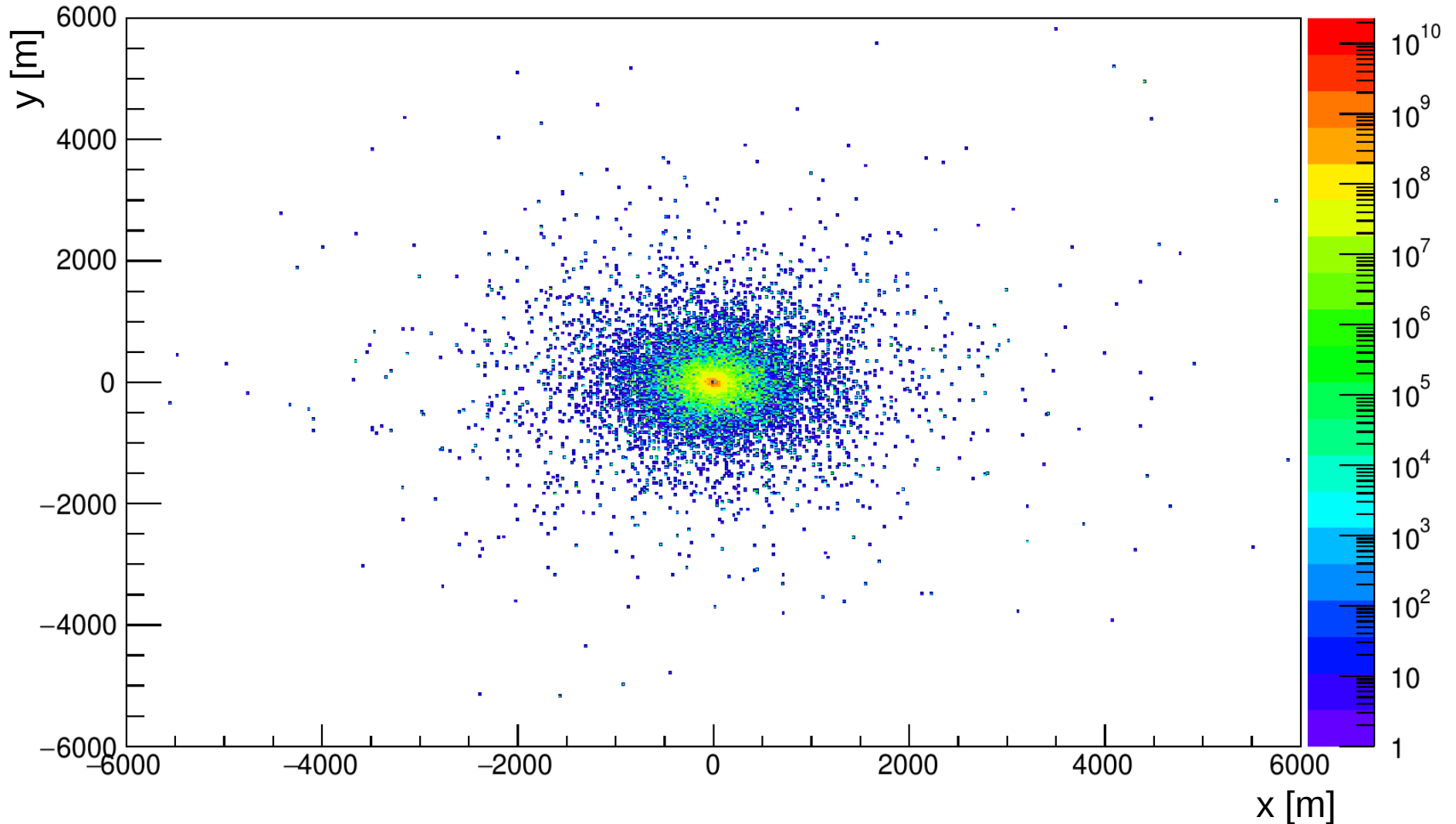


Particle Number Vs Altitude - Footprint

Cloud base: 6.0 km

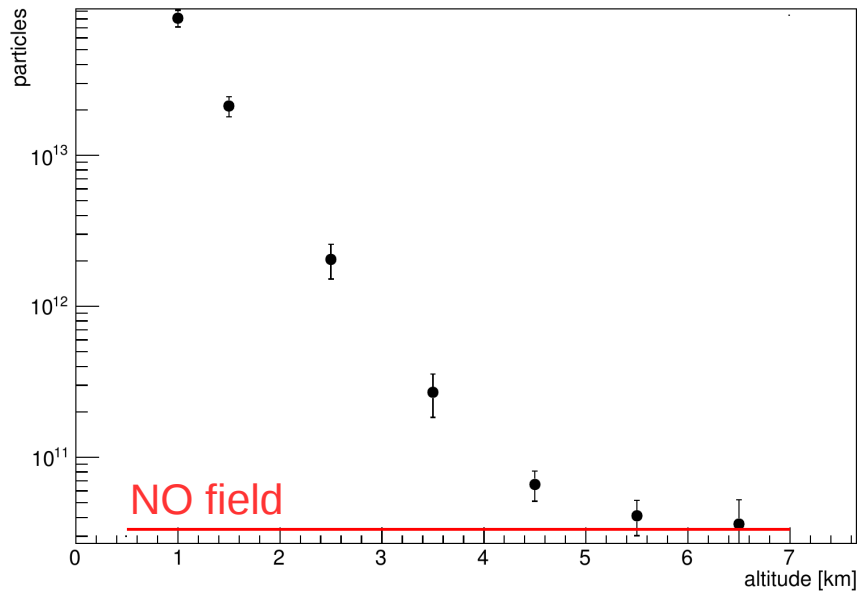


Particle Number Vs Altitude - Footprint NO field

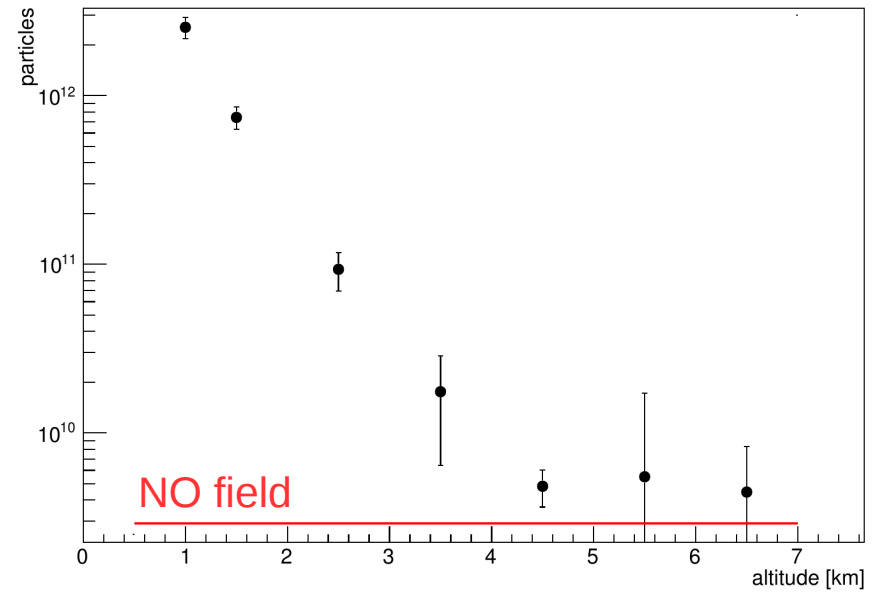


Particle Number Vs Altitude

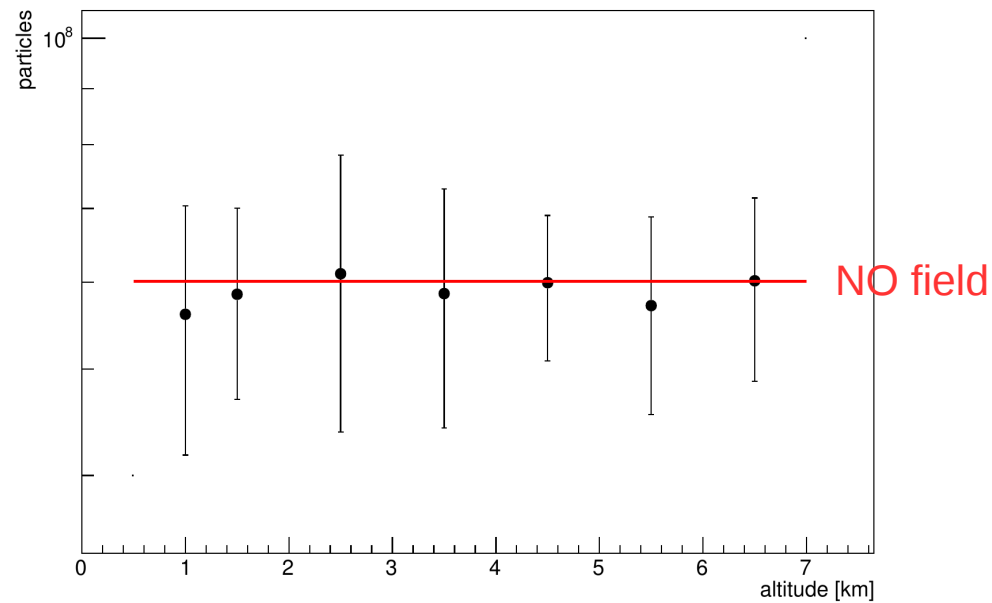
gamma



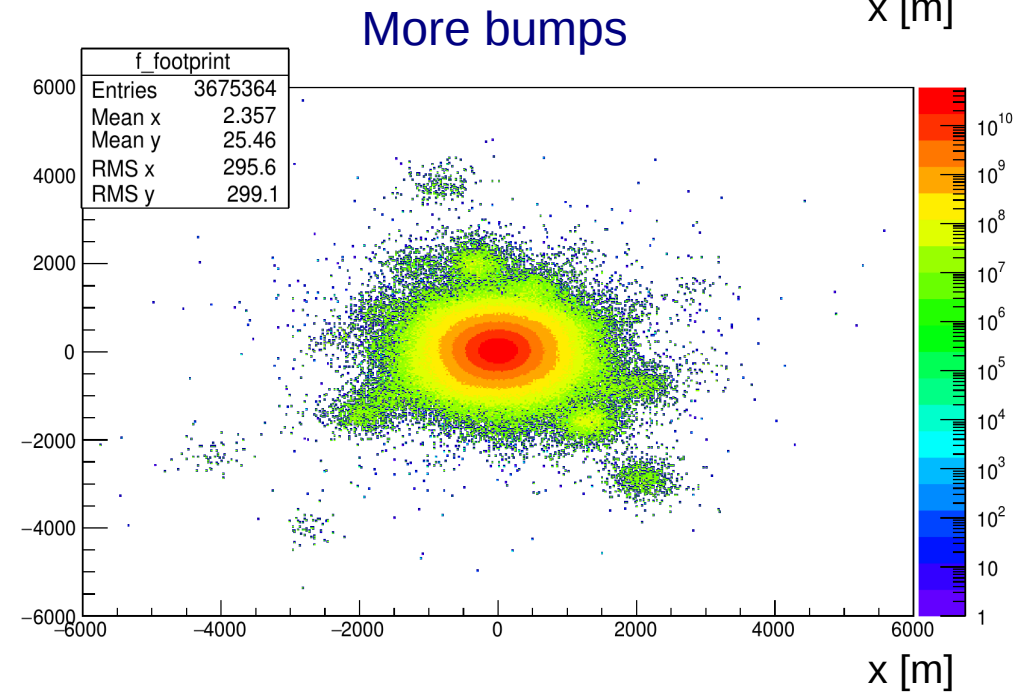
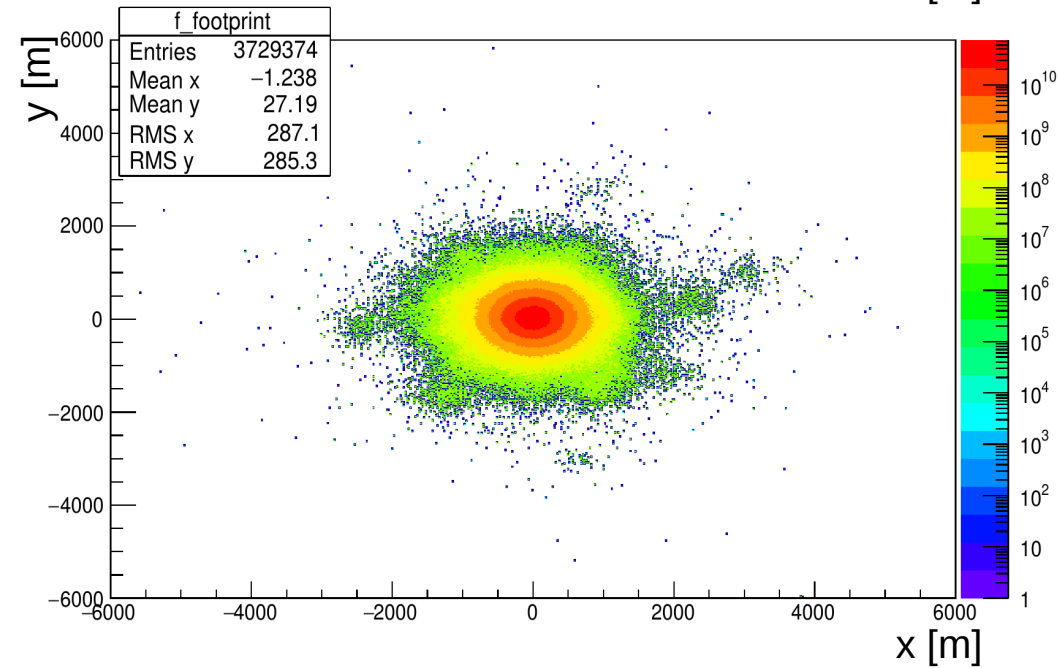
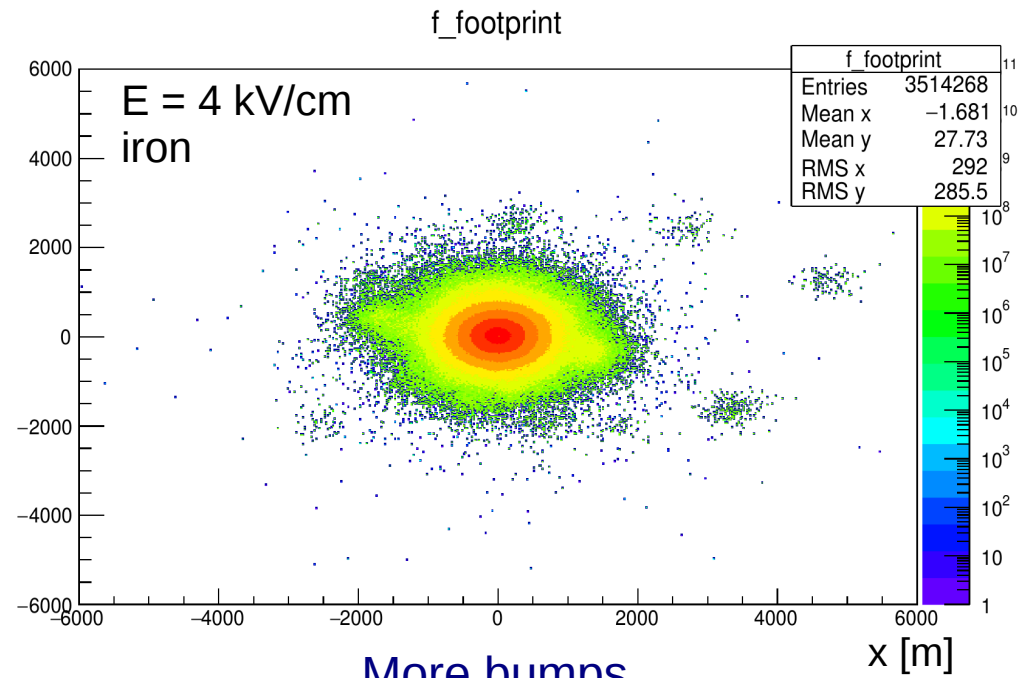
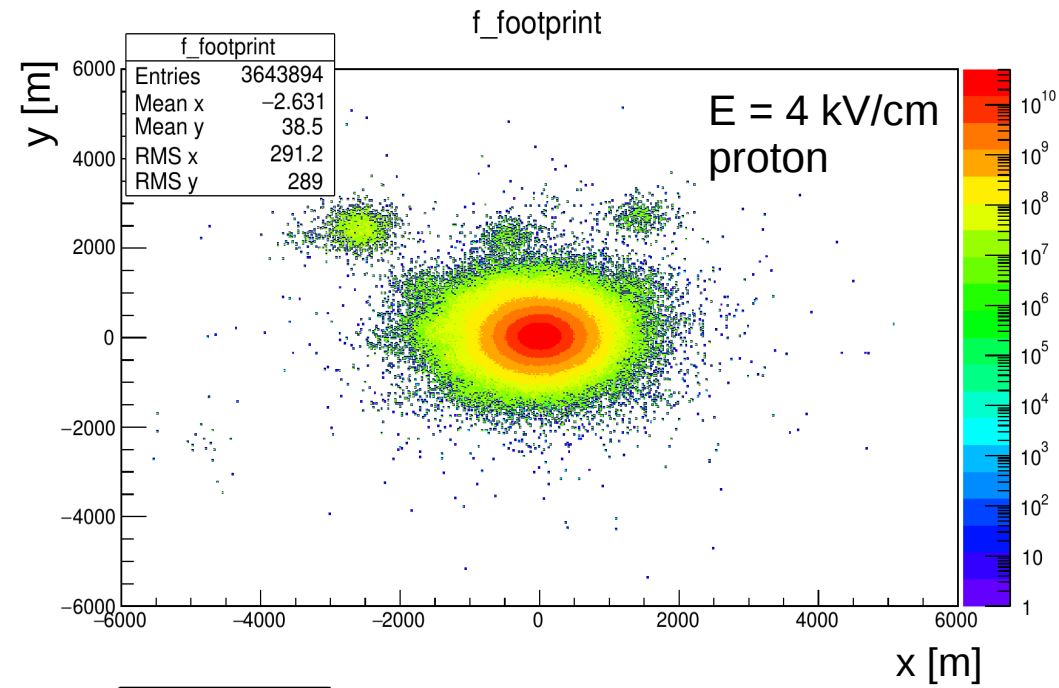
e+/e-



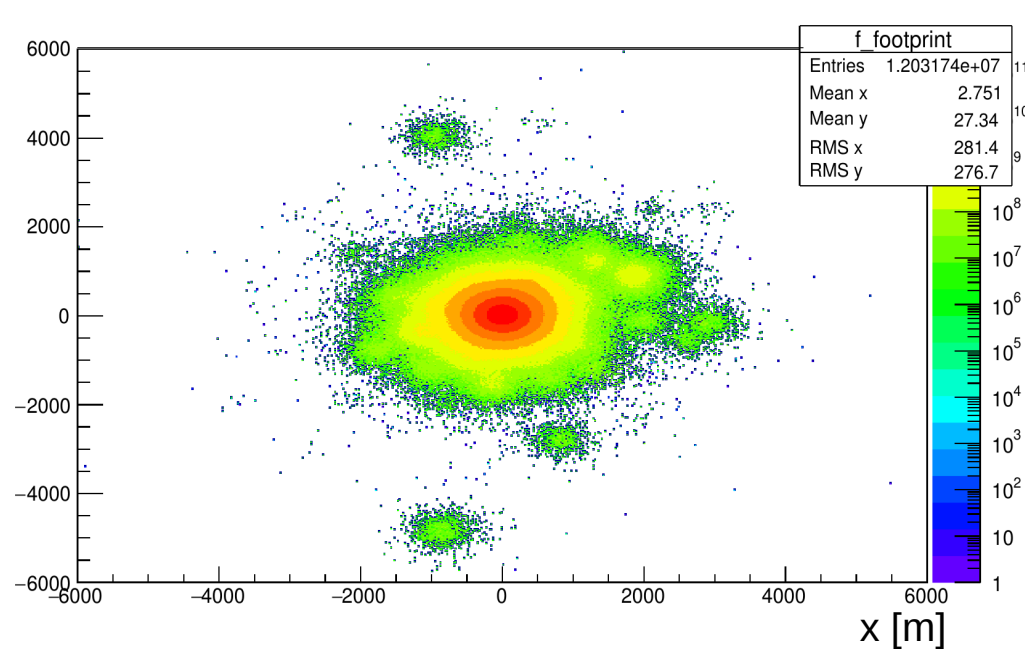
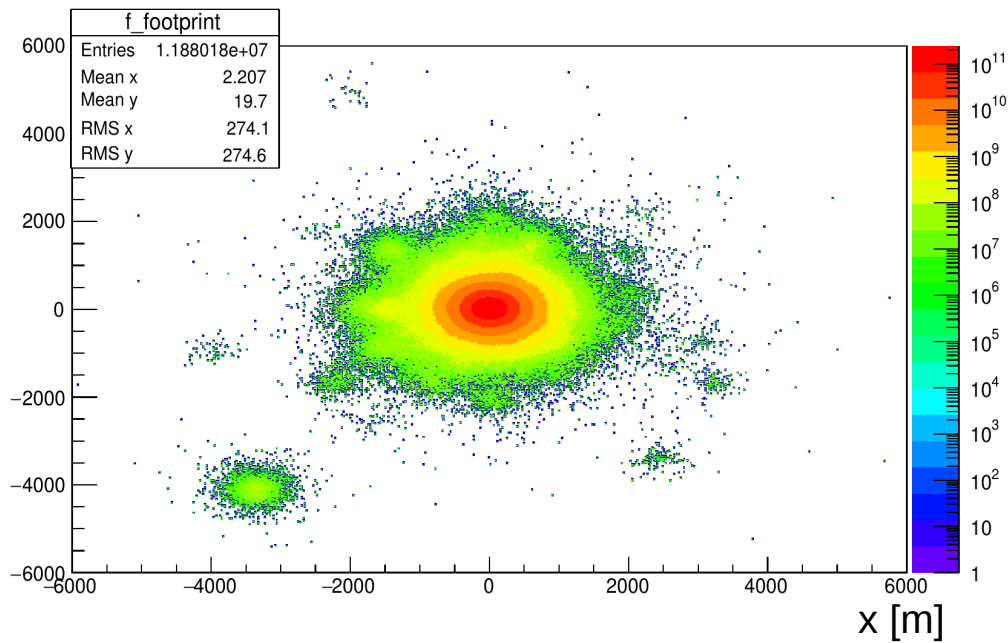
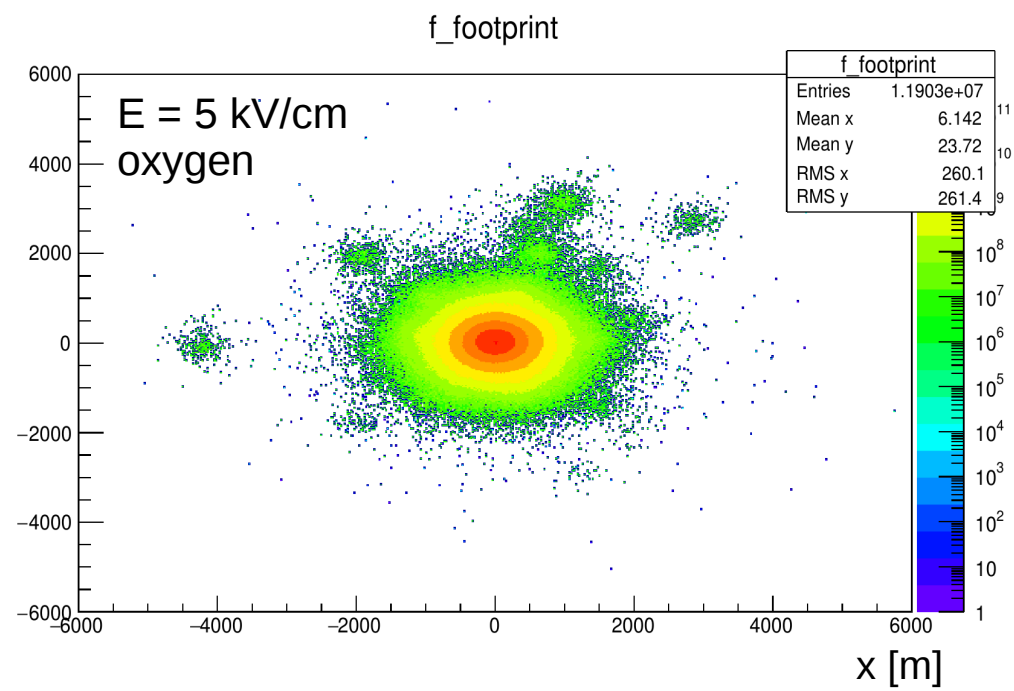
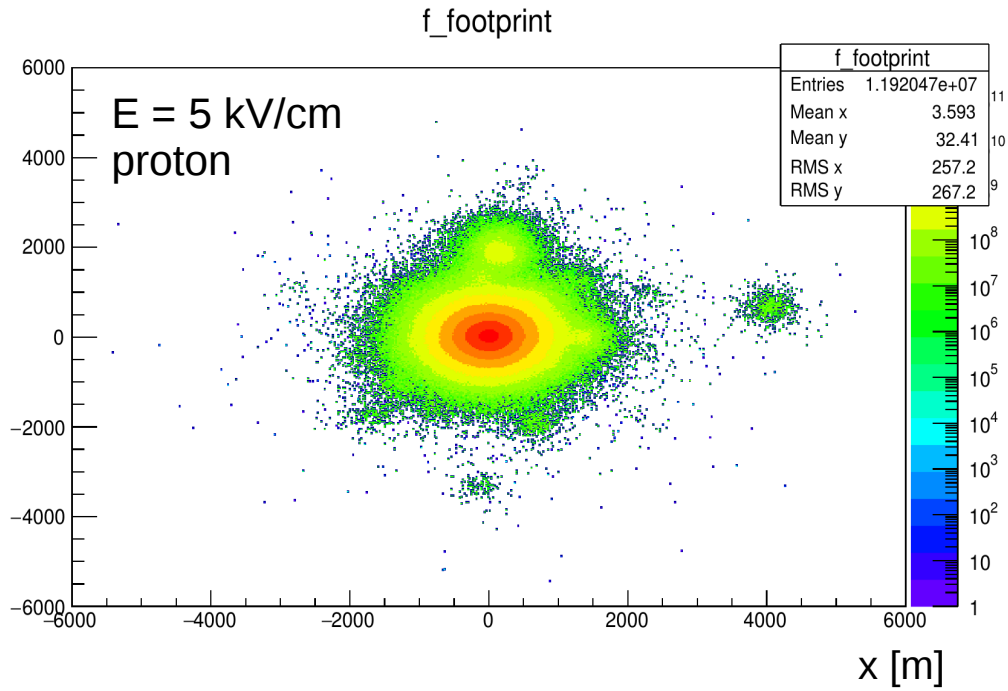
mu+/mu-



Corsika Footprint – Proton/Iron

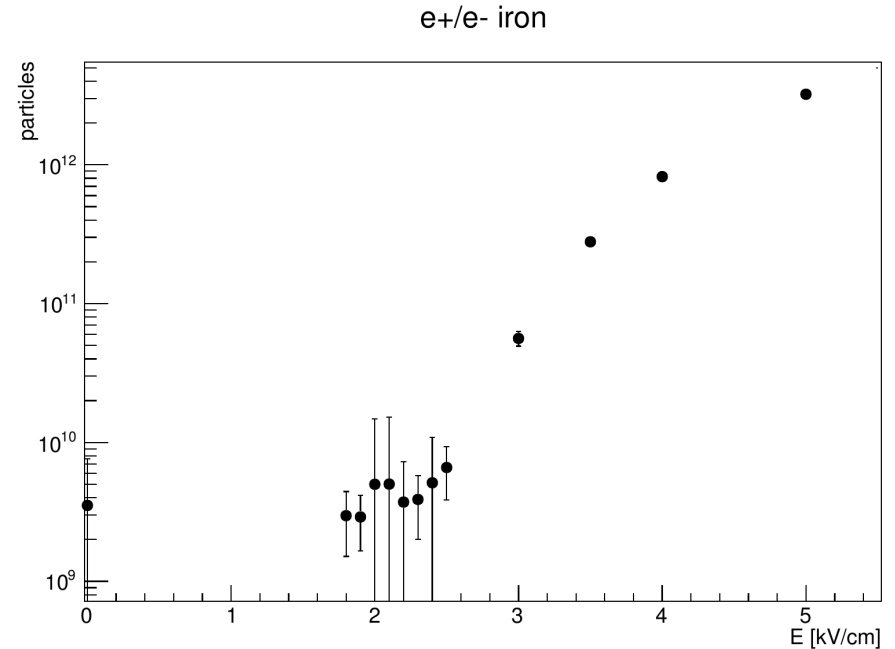
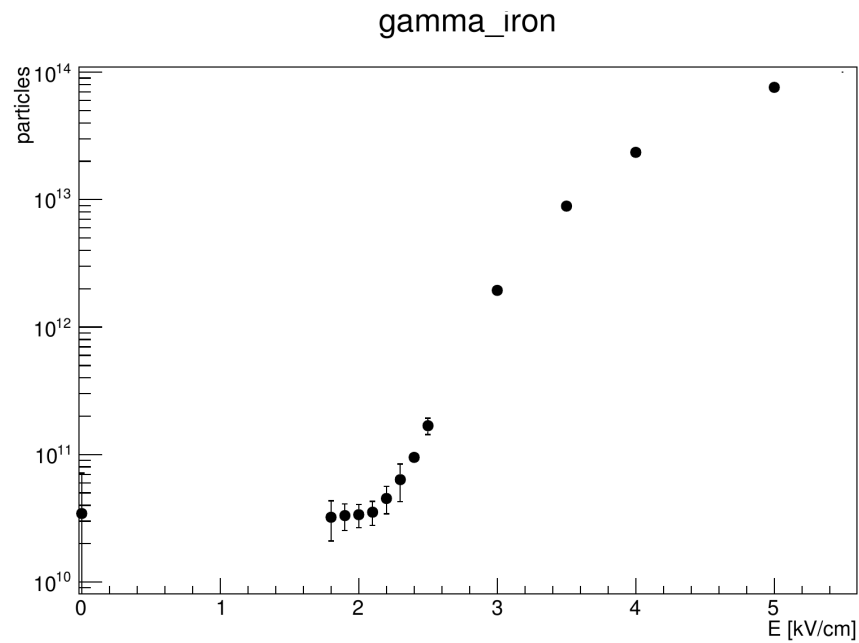
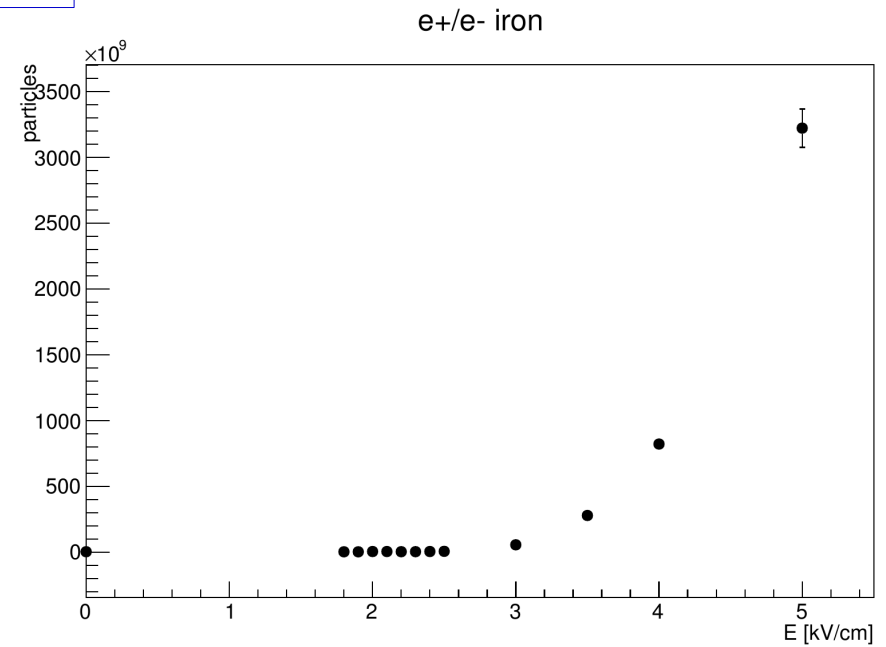
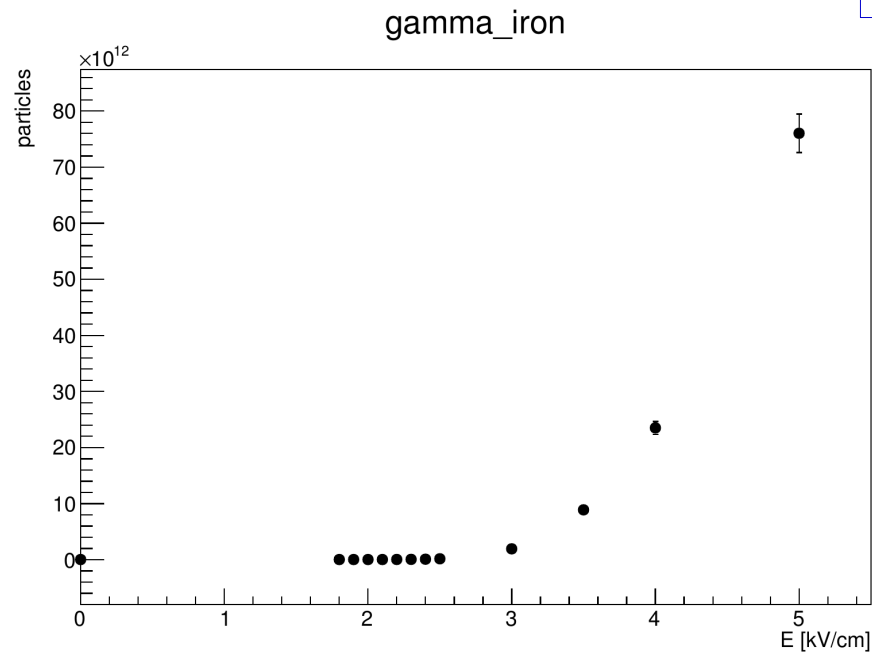


Corsika Footprint – P/Ox 5 kV/cm

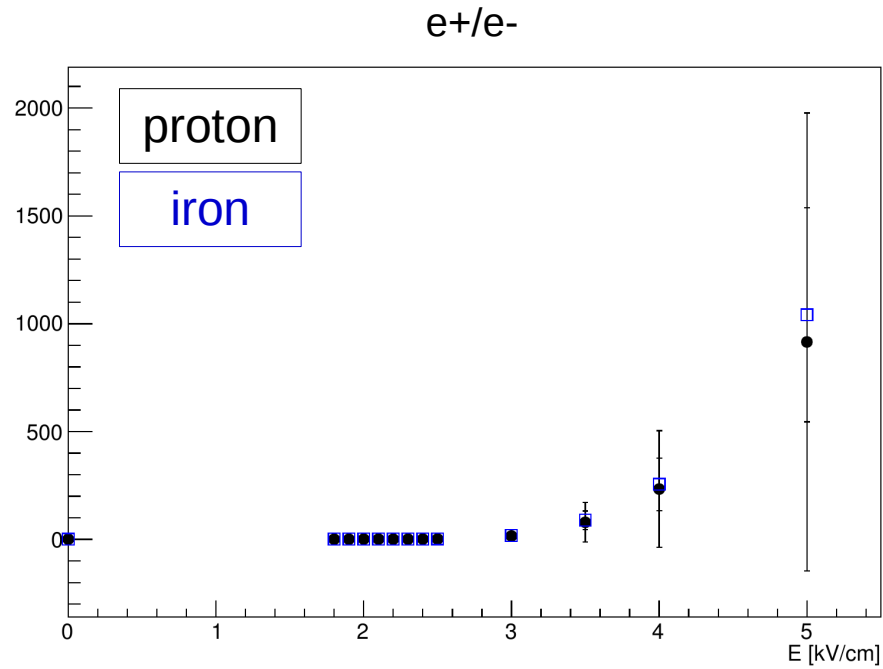
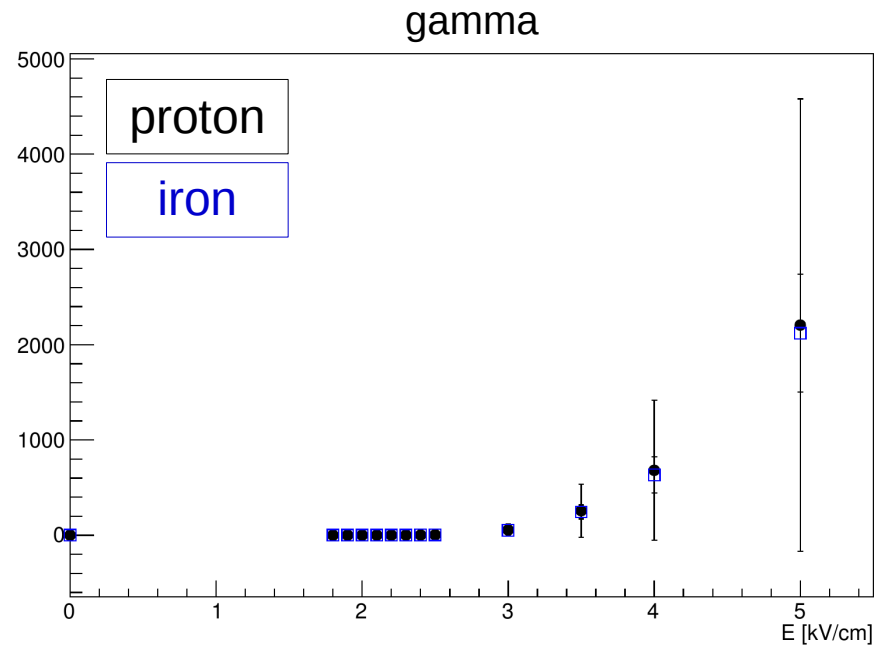


Particle Number and Primary Mass

iron

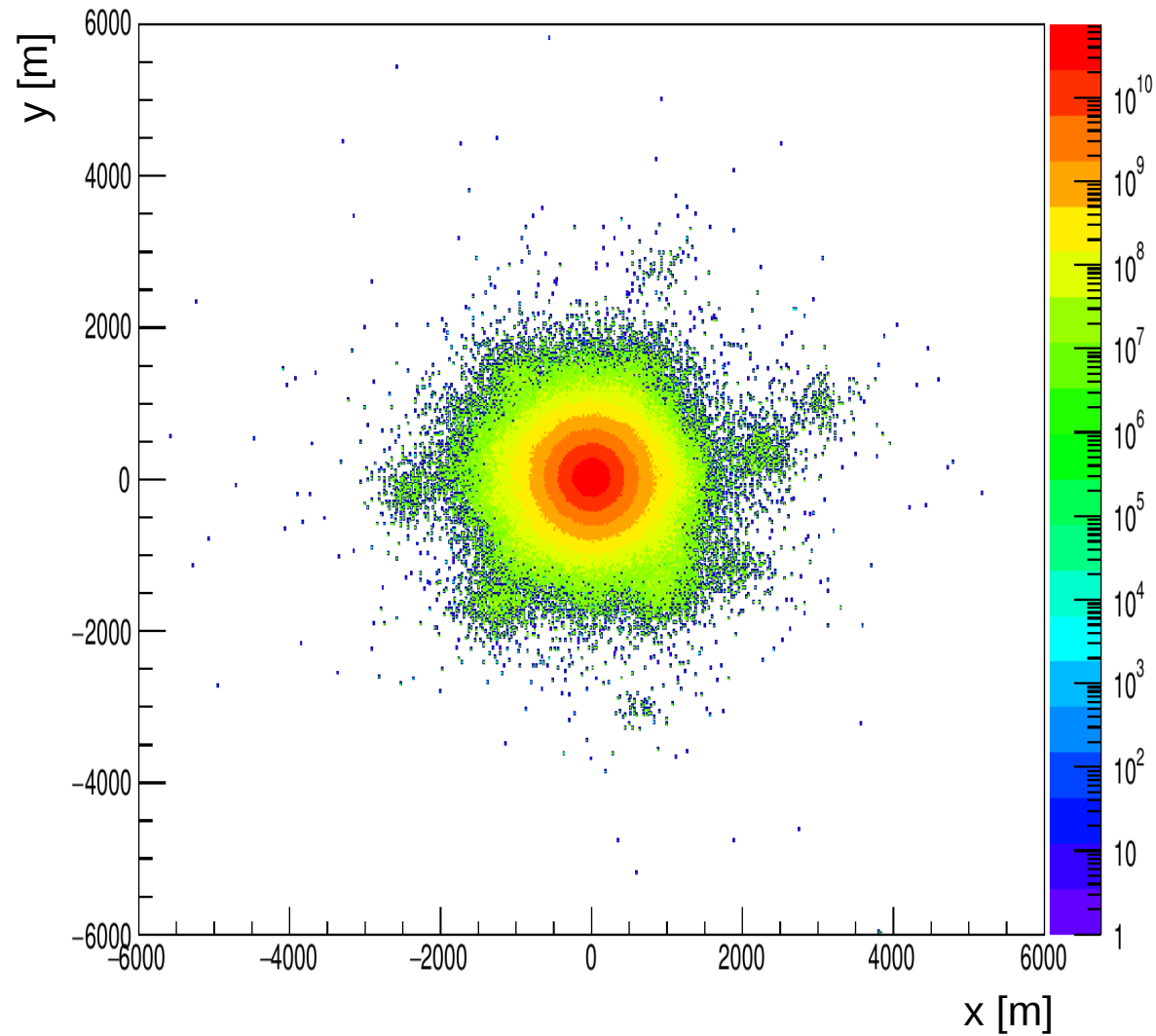


Particle Number and Primary Mass



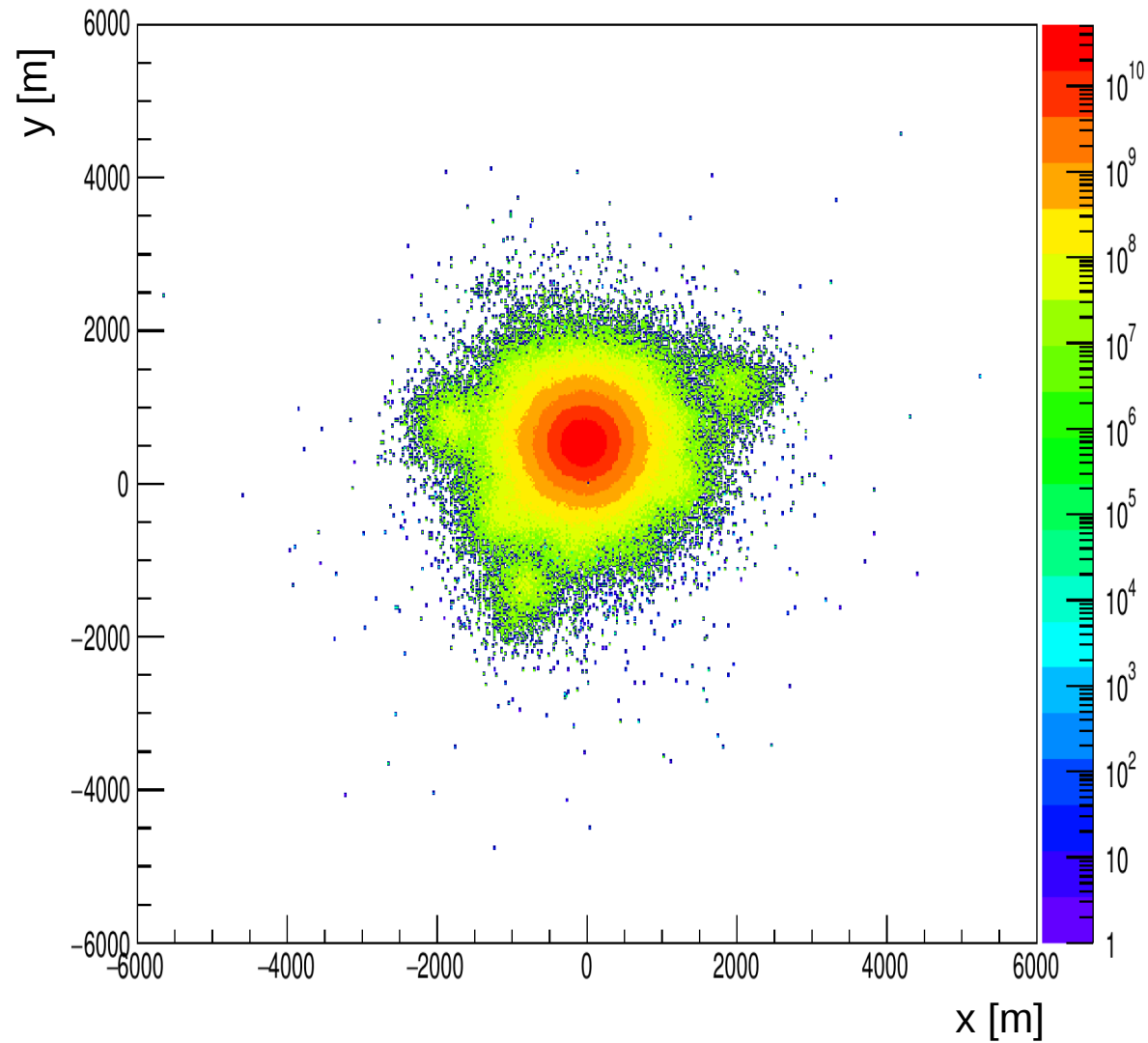
Particle Number Vs Zenith Angle

$\theta=0^\circ$



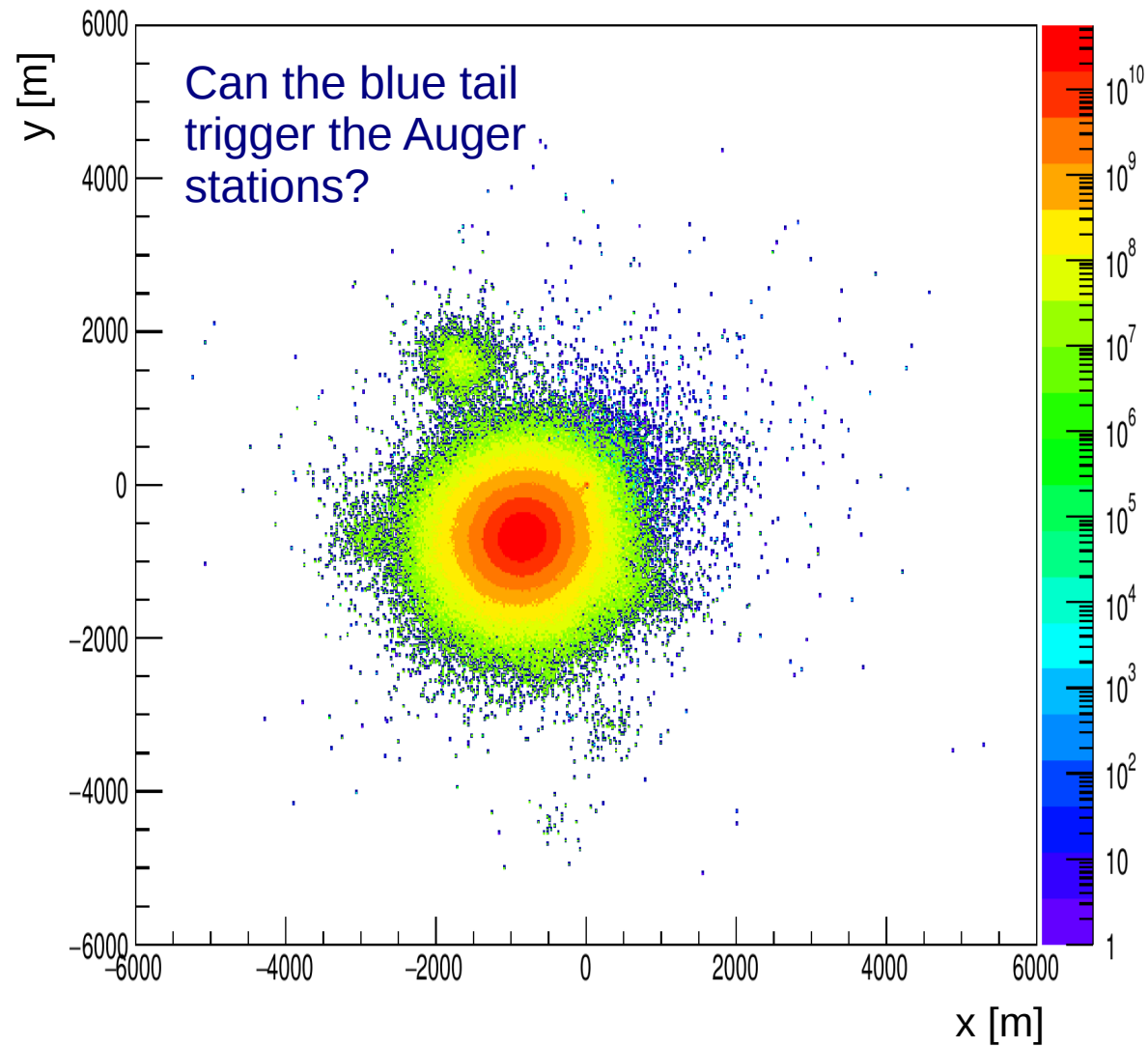
Particle Number Vs Zenith Angle

$\theta=15^\circ$



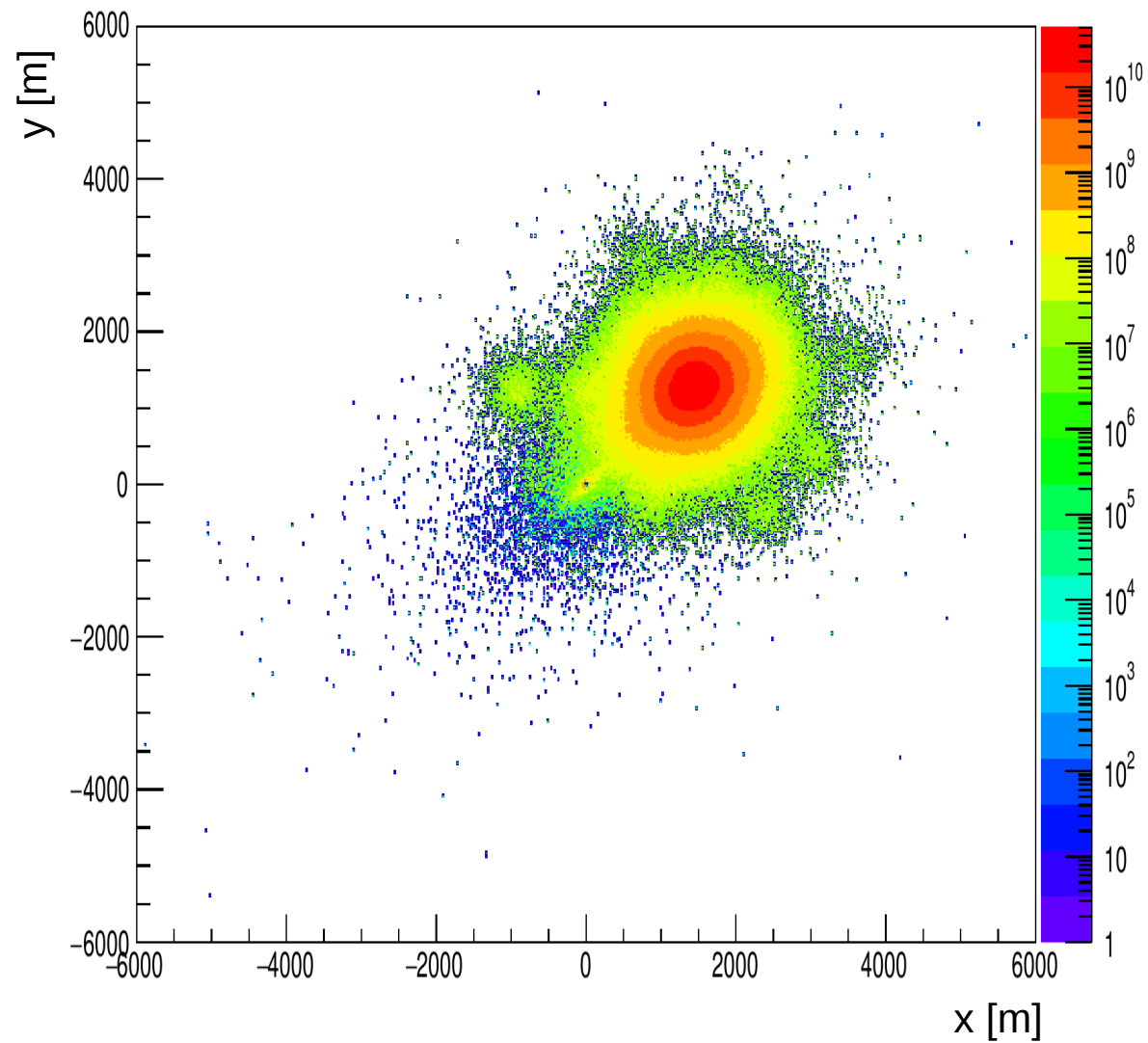
Particle Number Vs Zenith Angle

$\theta=30^\circ$



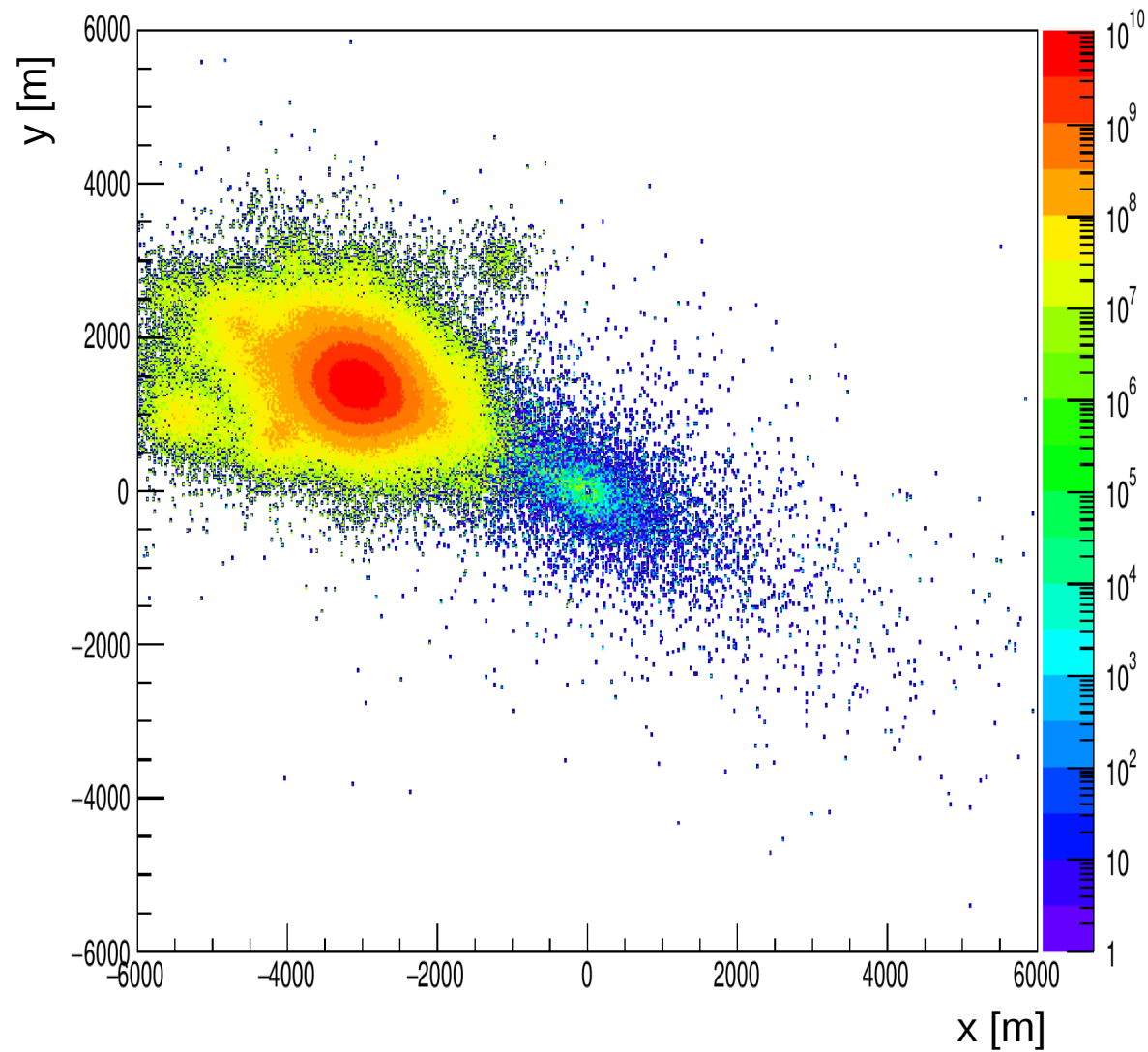
Particle Number Vs Zenith Angle

$\theta=45^\circ$

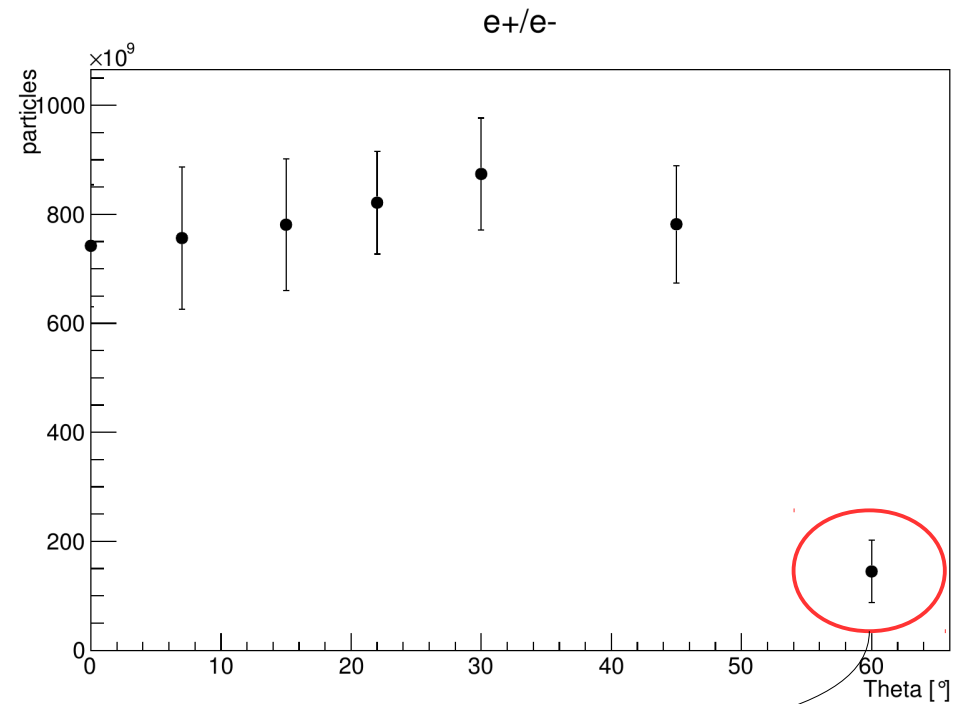
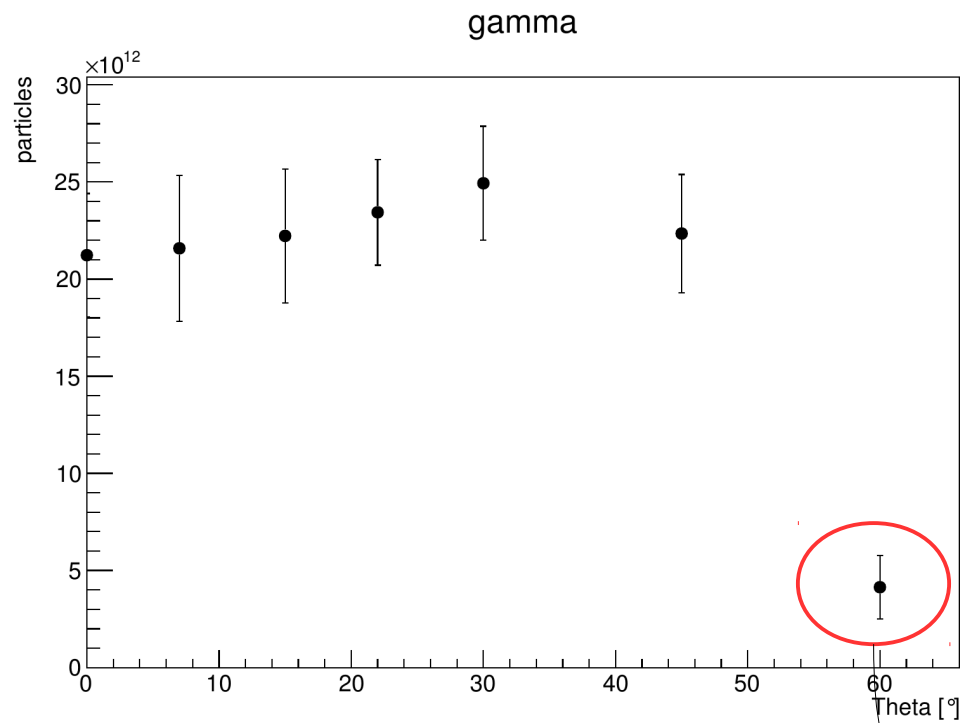


Particle Number Vs Zenith Angle

$\theta=60^\circ$



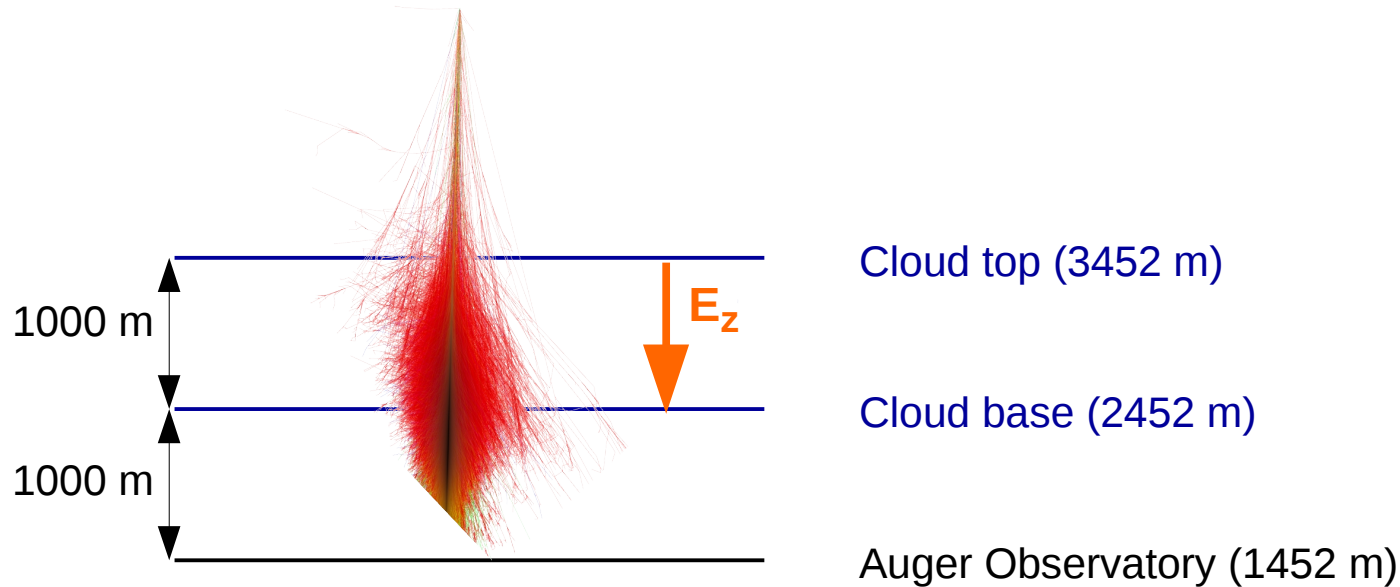
Particle Number Vs Zenith Angle




Atmospheric Absorption


At the other zenith angles, the flux at the ground is constant within uncertainties. More statistics and further studies are necessary.

Inverted Electric Field



NO El Field → gamma, e-, e+, μ : 3.34e+10, 1.99e+09, 9.13e+08, 6.01e+07

E = 4 kV/cm  → gamma, e-, e+, μ : 2.12e+13, 6.08e+11, 1.34e+11, 5.85e+07

E = 4 kV/cm  → gamma, e-, e+, μ : 5.71e+10, 3.14e+09, 3.83e+09, 6.32e+07

With the inverted electric field, there is a very small enhancement in gamma and positron number as expected.

Conclusions

- We have observed a big enhancement of gamma, electrons and positron fluxes at the ground when a shower crosses the electric field in a thunderstorm cloud;
- The footprint at the ground is larger than the shower footprint without electric field;
- The increase in the particle number at the ground is independent by the mass of the primary cosmic-ray and by its energy in the range $[10^{17} \text{ eV}, 10^{18} \text{ eV}]$;
- Electric fields in high clouds (cloud base at more than 4 km) don't affect the fluxes at the ground.

To do ...

- Scan in electric field direction?
 - Non uniform electric field;
 - Studies of correlation between X_{max} position and enhancements at the ground.
- ▶ Studies are in progress to understand if this model can explain Auger SD peculiar events or not
- ▶ and if these enhancements can affect cosmic-ray reconstruction.