About the nature of anomalous events in the TUS detector

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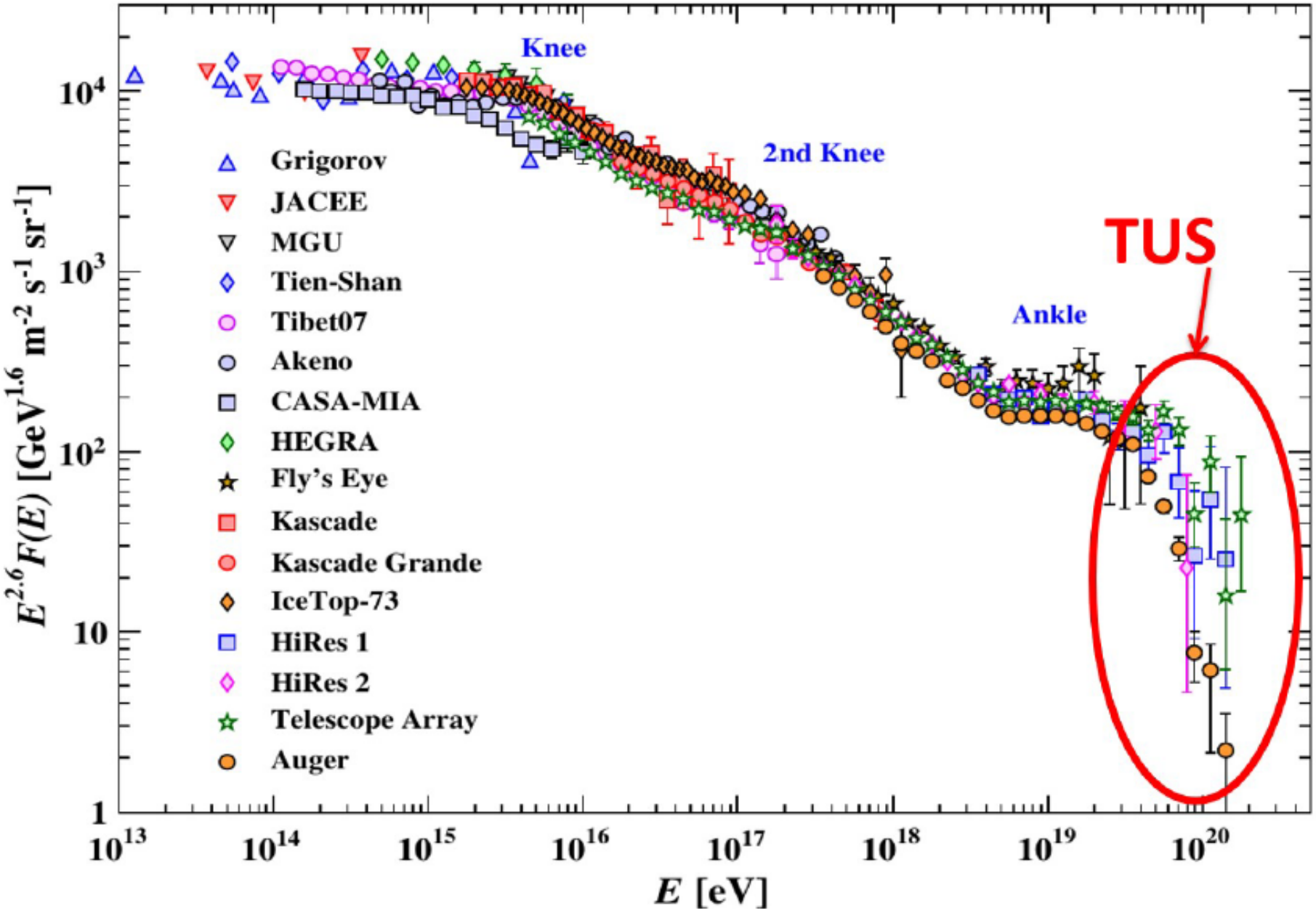
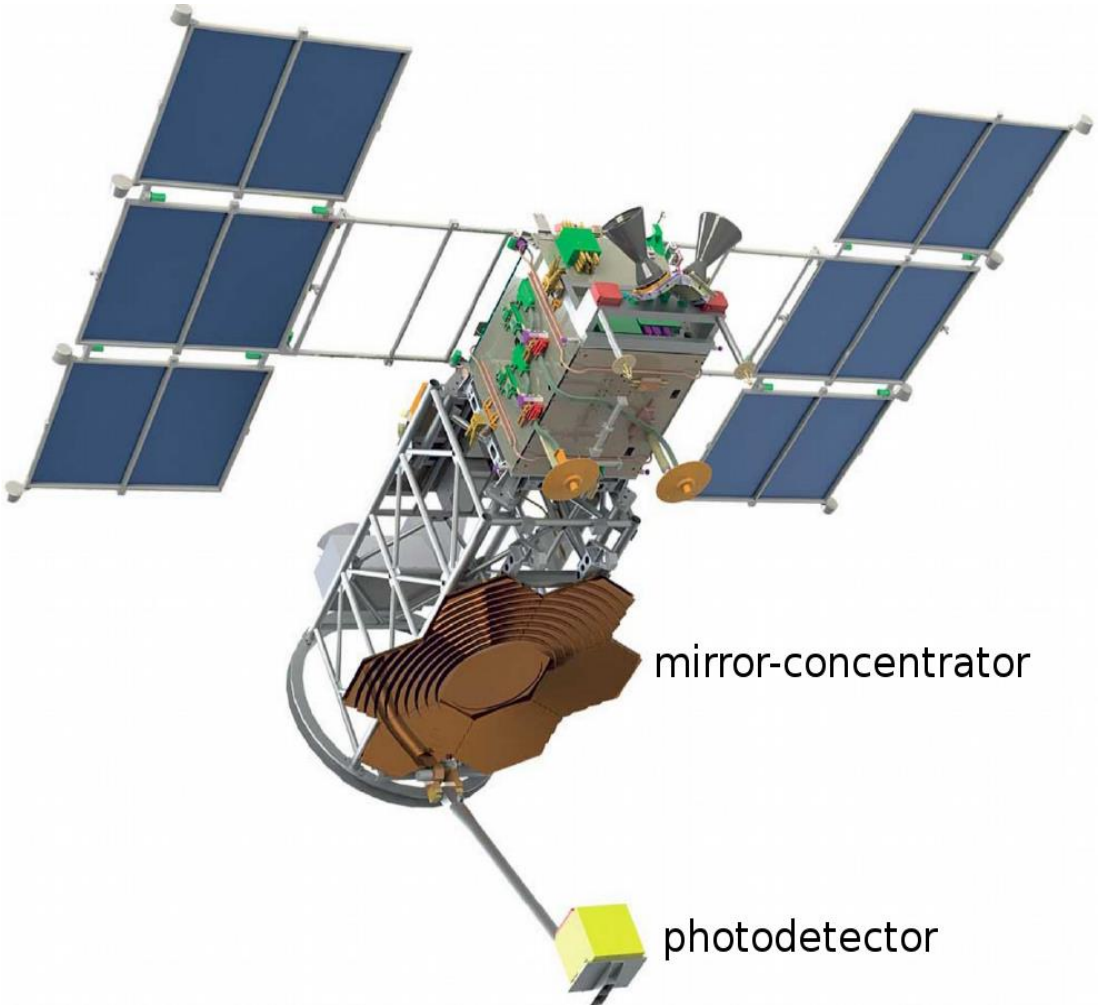
Cosmic rays spectrum

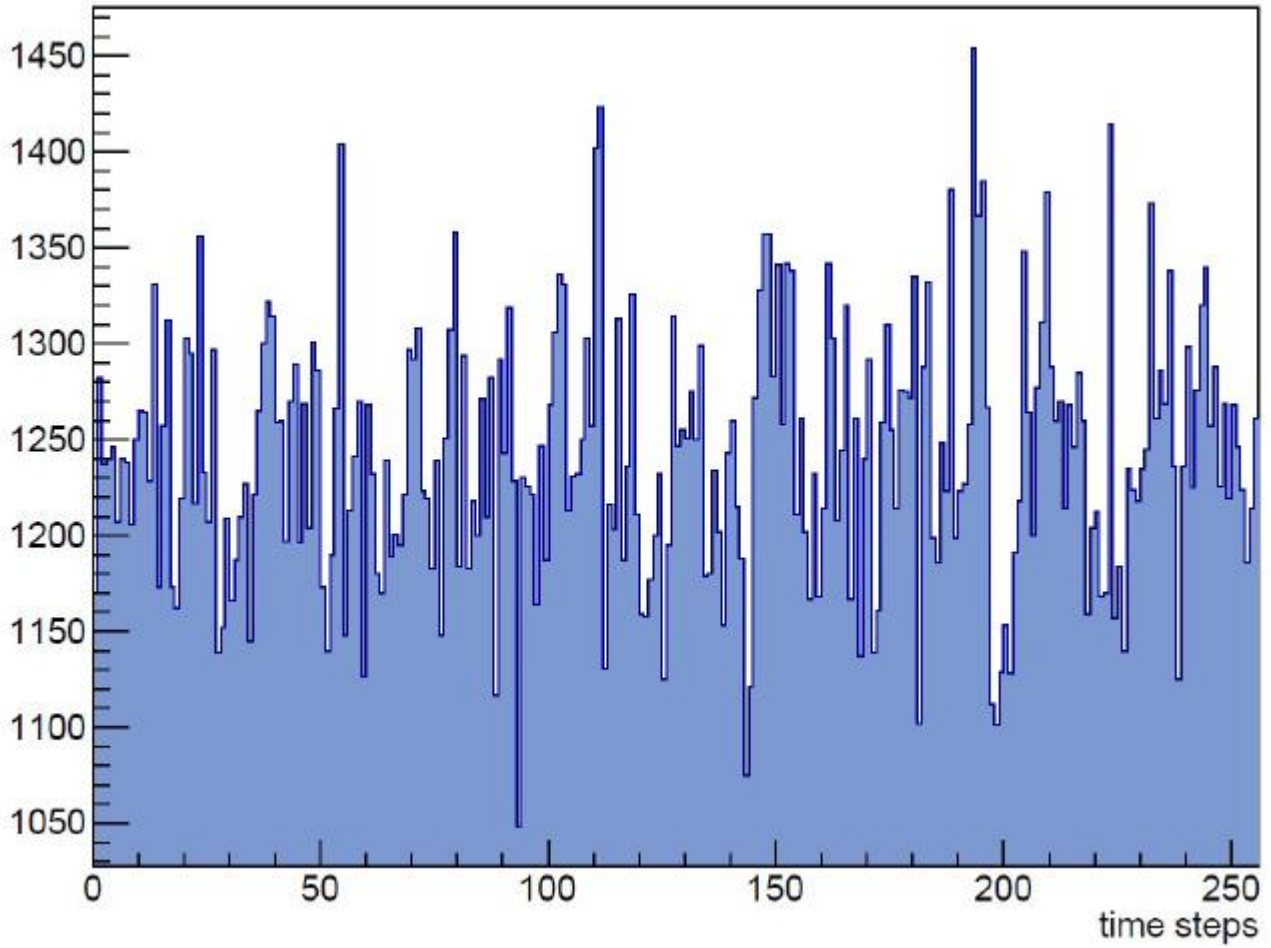


Schematic view of the TUS detector aboard “Lomonosov” satellite



Mass	<60 kg
Power	65 W
Data rate	200 Mbytes/day
Number of pixels	16x16 PMTs
FOV	±4,5 degree
Duty cycle	30%
Altitude	500 km
Pixel:	10 mrad
Mirror area	1,8 m2
Focal distance	1,5 m
Period	94 min

Background signal in TUS data



Time dependence of the integral amplitude of the background event signal

EAS candidate event

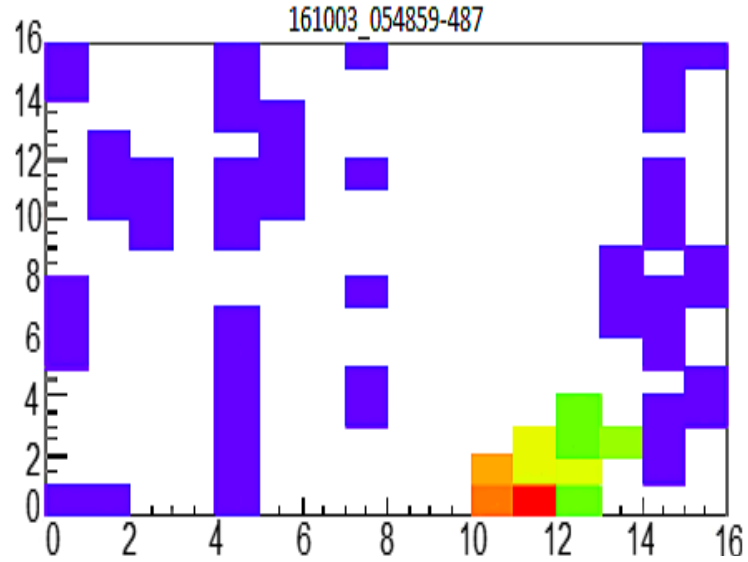
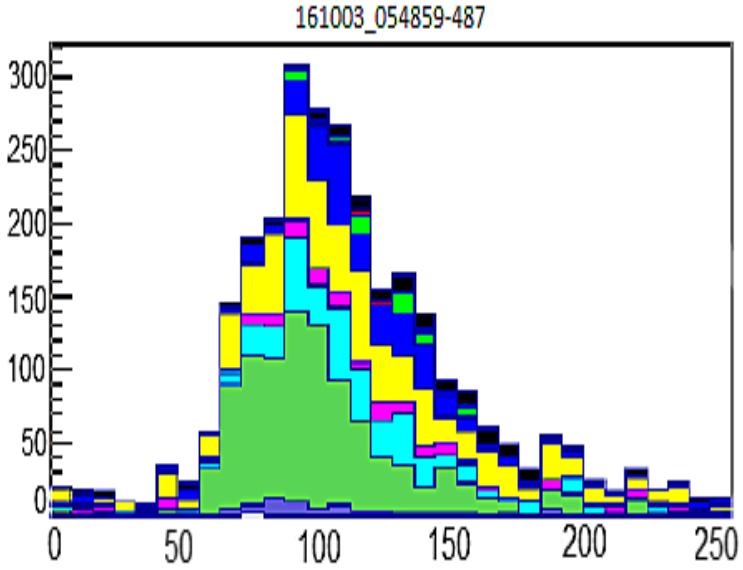
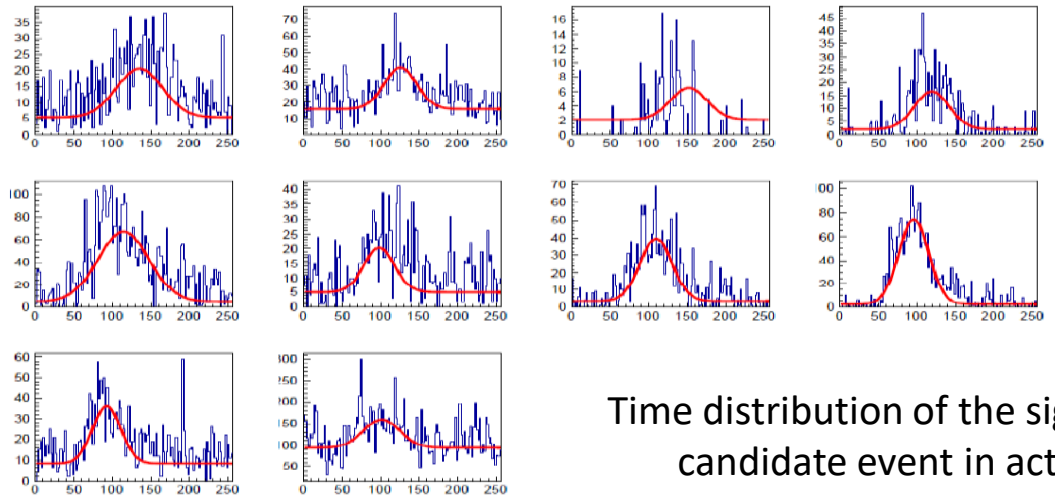


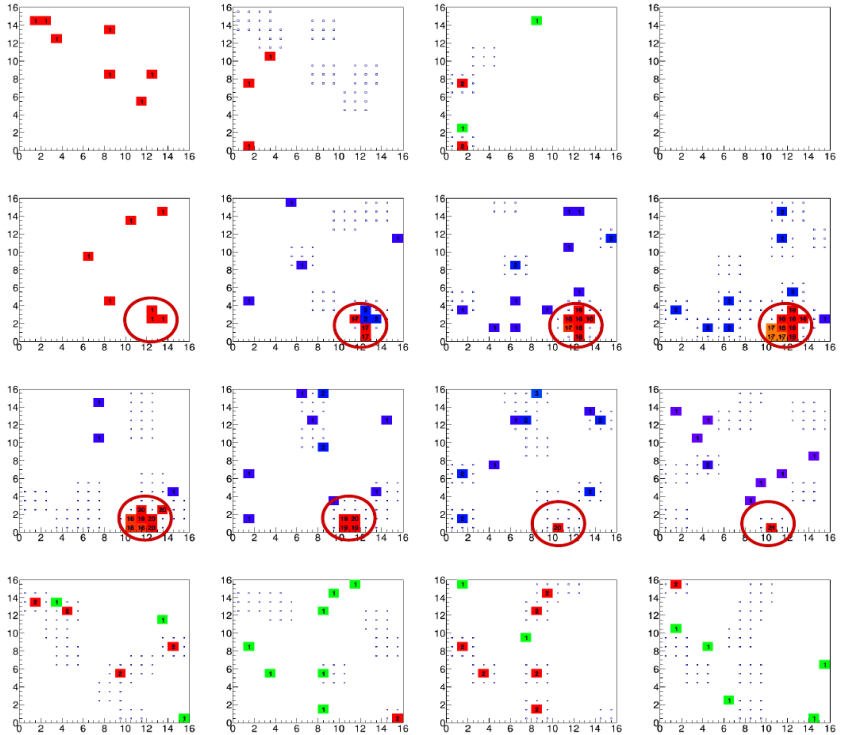
Image of the photodetector matrix with active pixels



Stack-histogram of this event

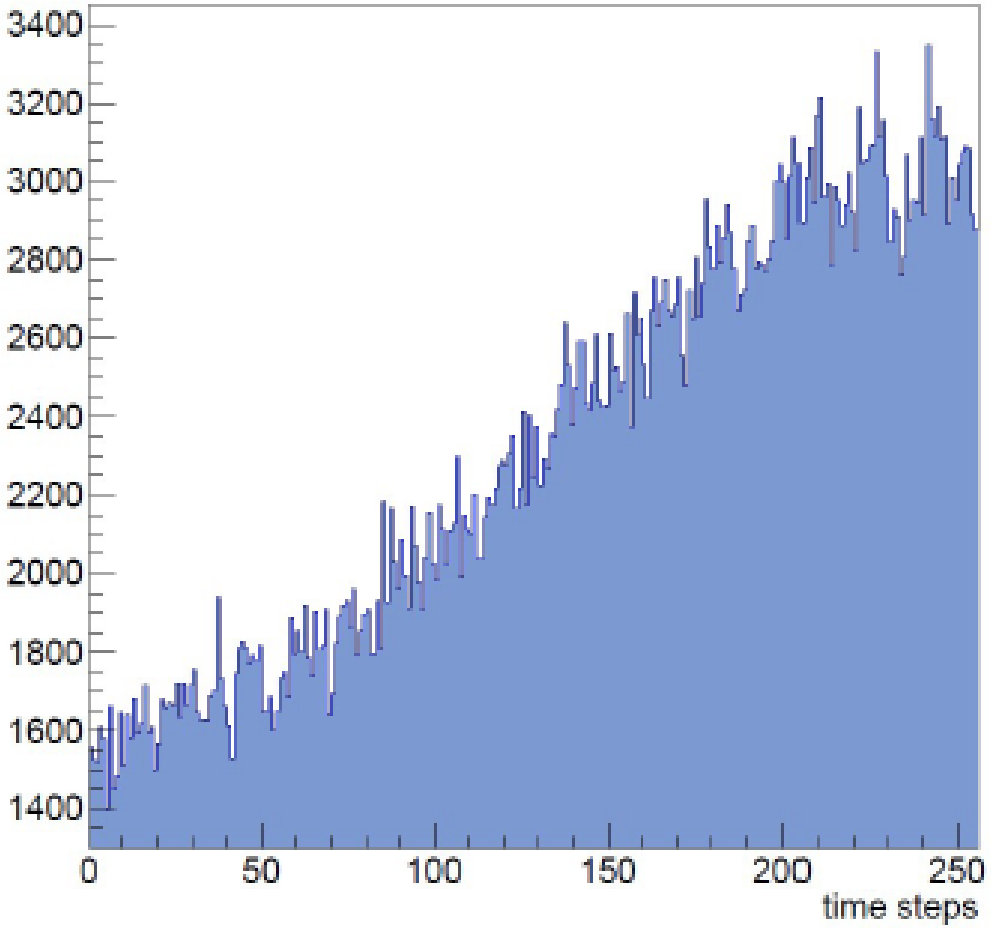


Time distribution of the signal from the candidate event in active pixels

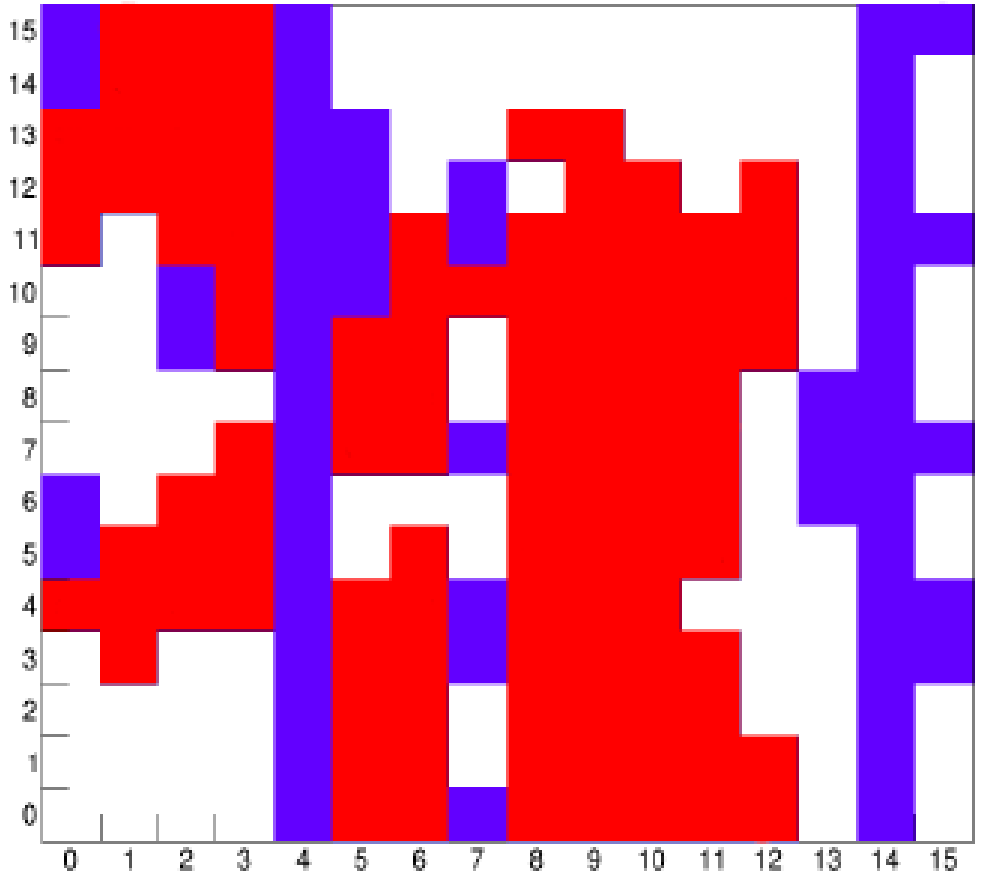


The image of the triggered pixels on a event map-plot with step 16 x 0.8 µs

Event of the thunderstorm nature



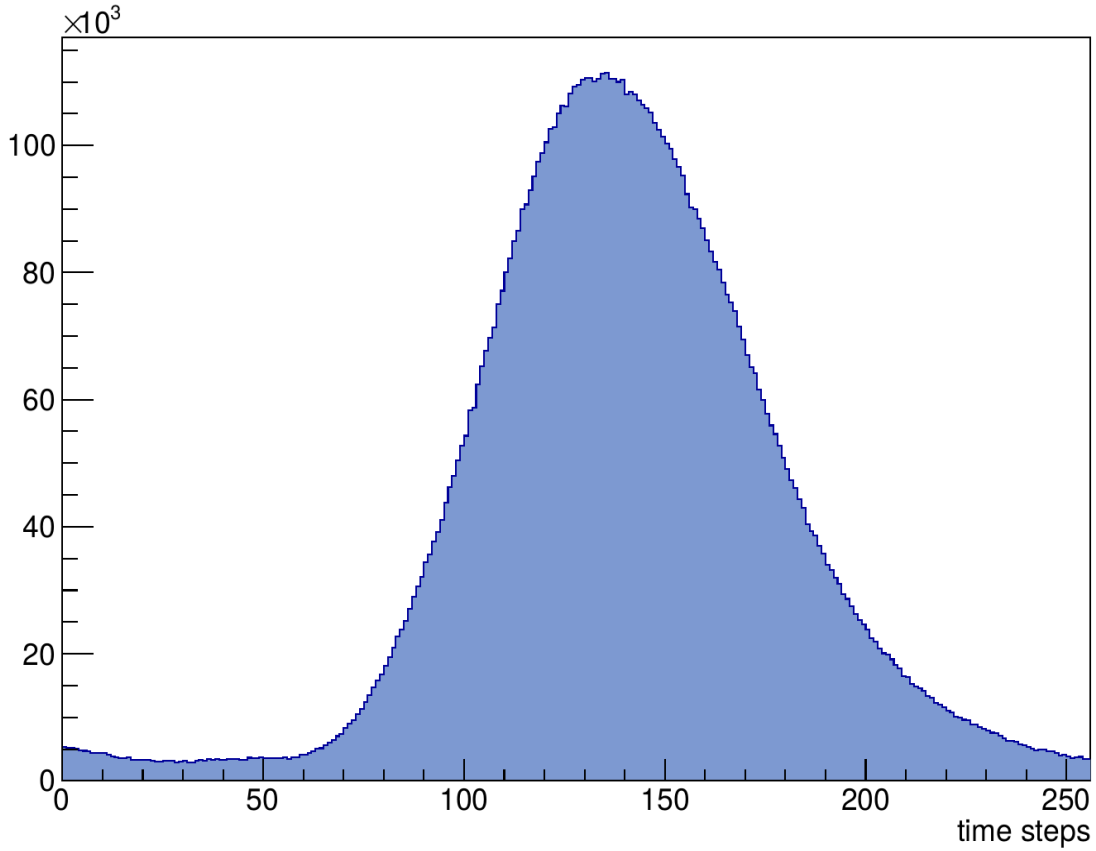
Time dependence of integral amplitude of the signal



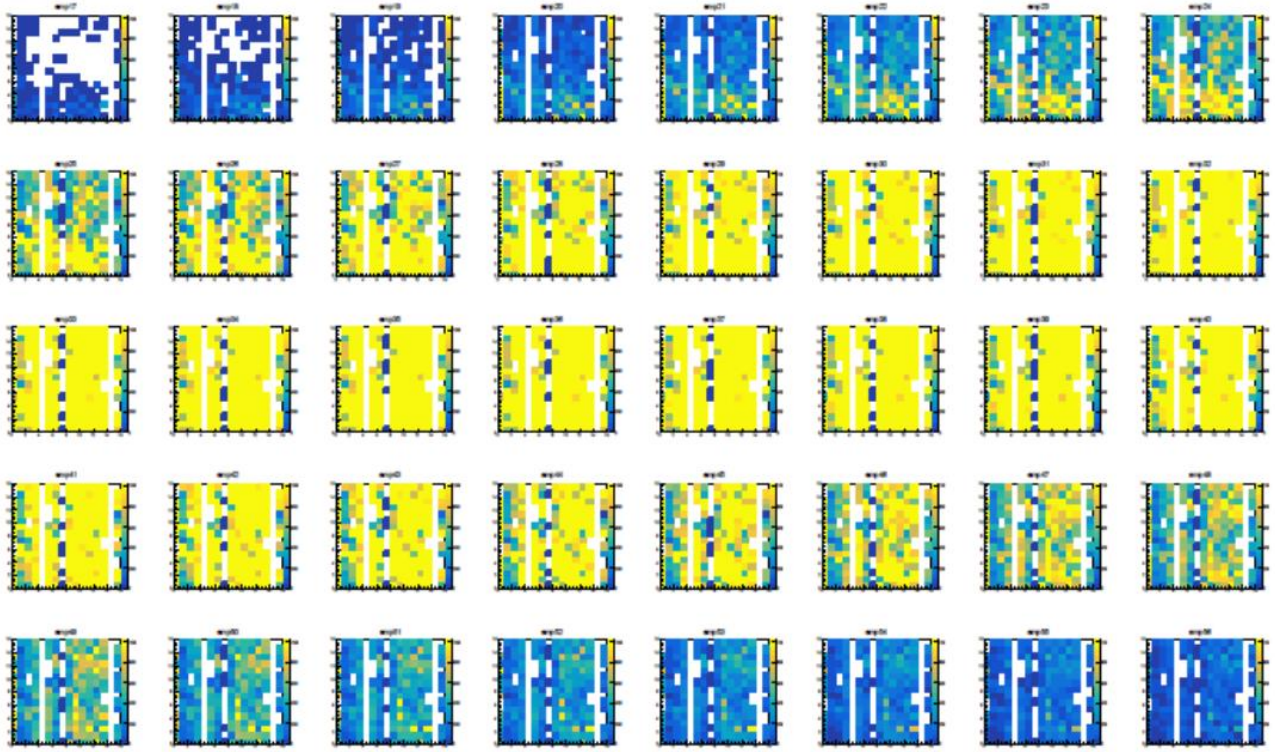
Matrix of the photodetector with dead PMT and hitted PMT’s

Anomalous events

Event №170818-072



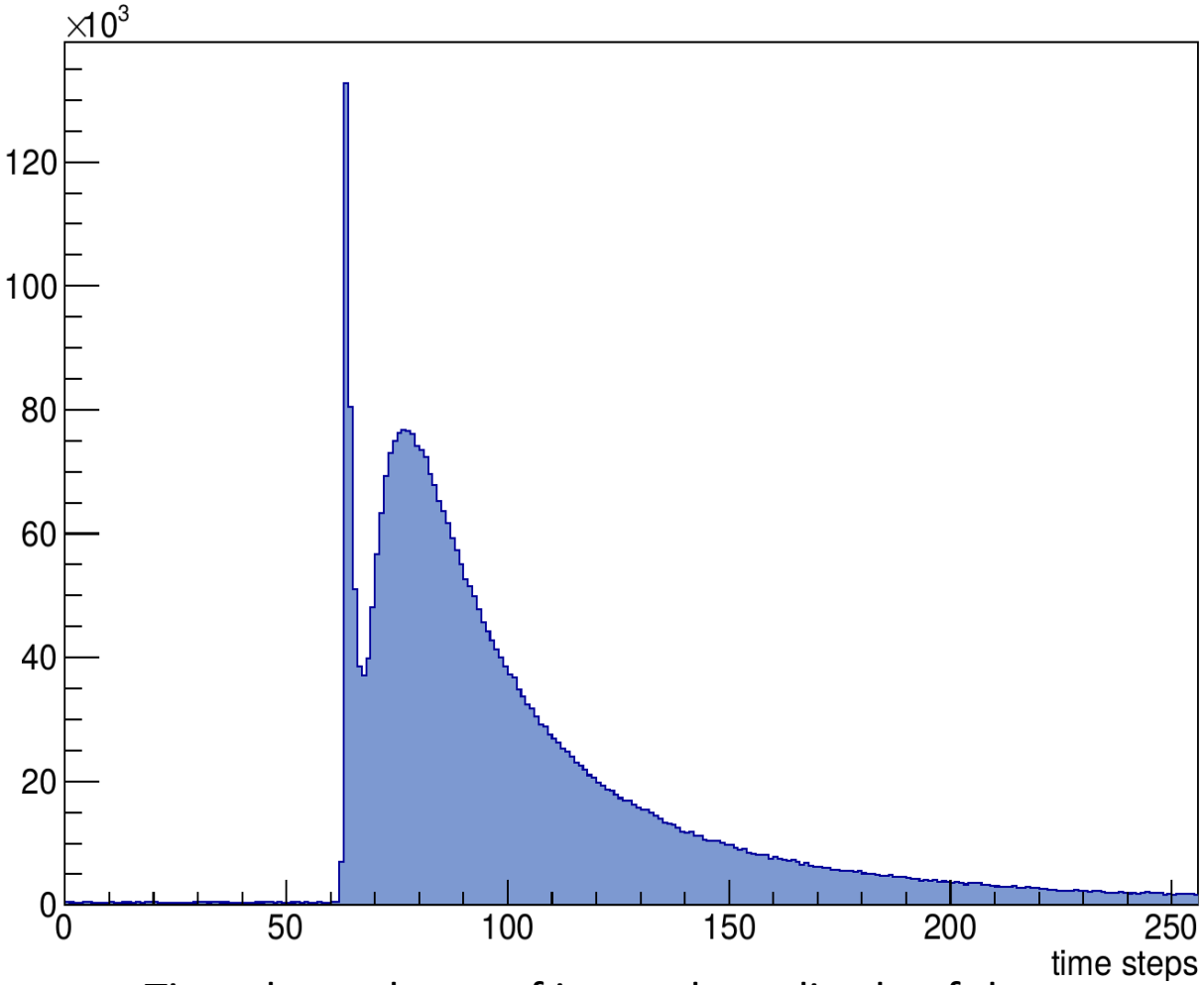
Time dependence of integral amplitude of the signal



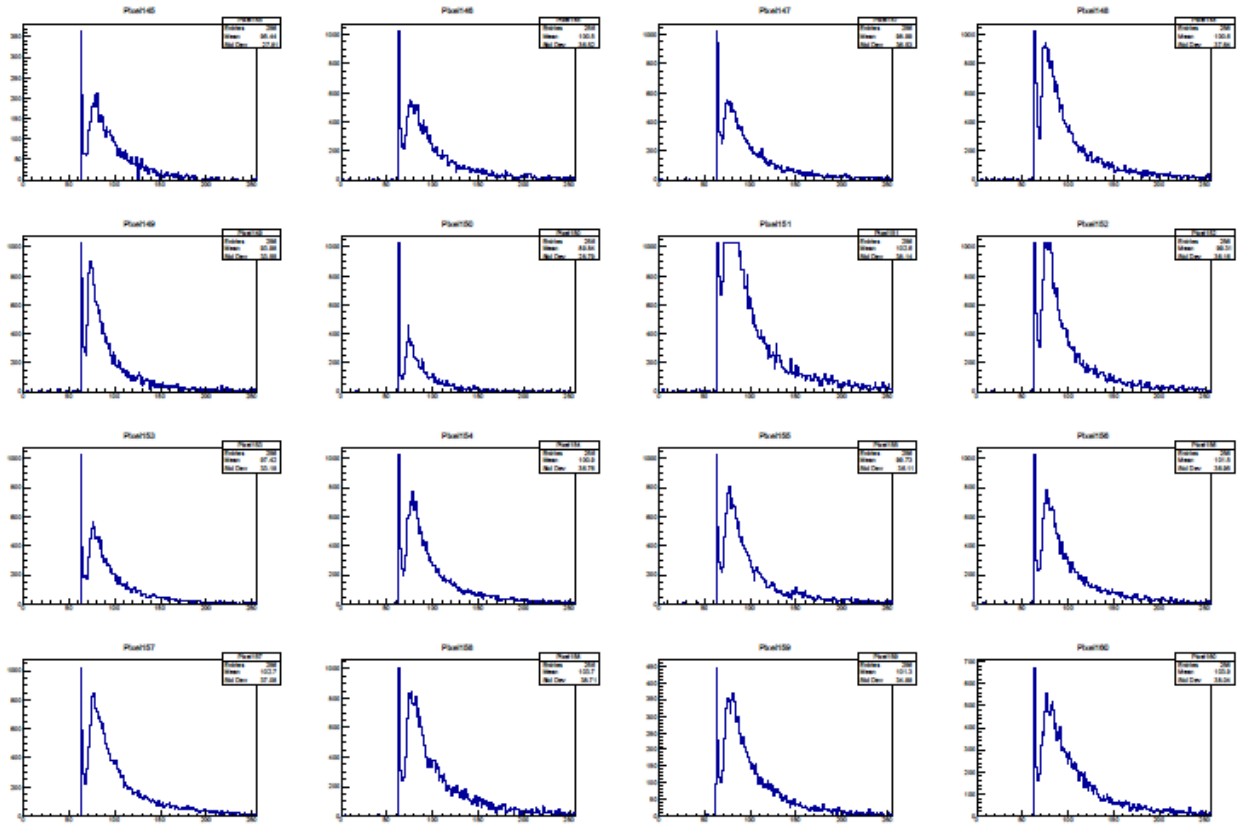
The image of the triggered pixels on a event map-plot with step 4 x 0.8 μs

Hybrid events

Event №170728-234



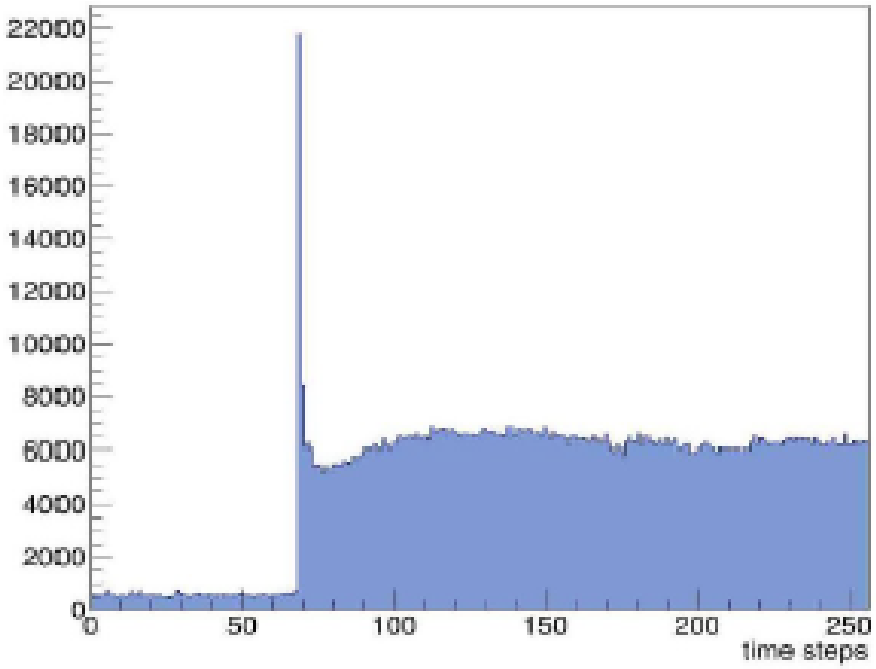
Time dependence of integral amplitude of the signal



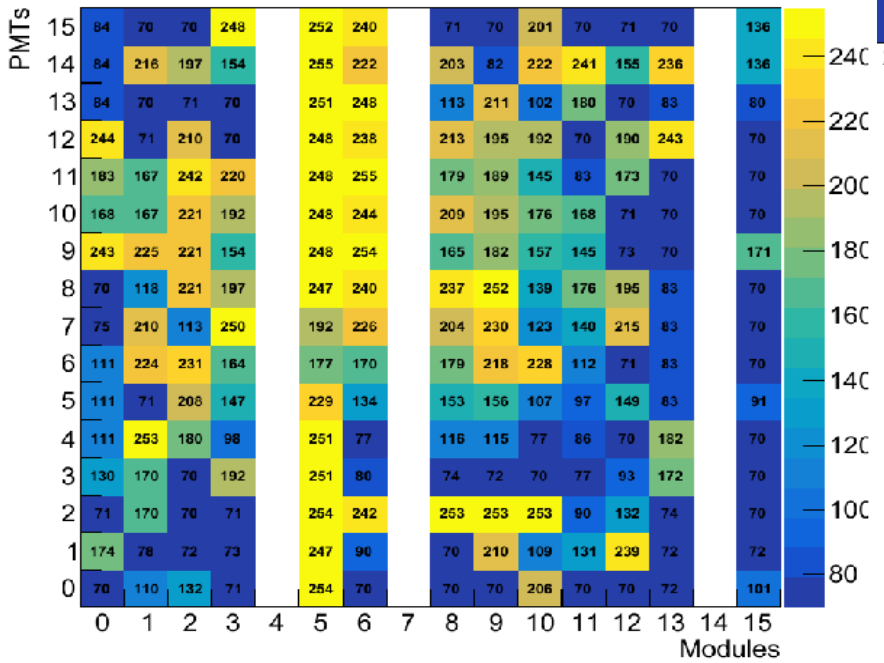
Time dependence of amplitude in 10th module

Combined events

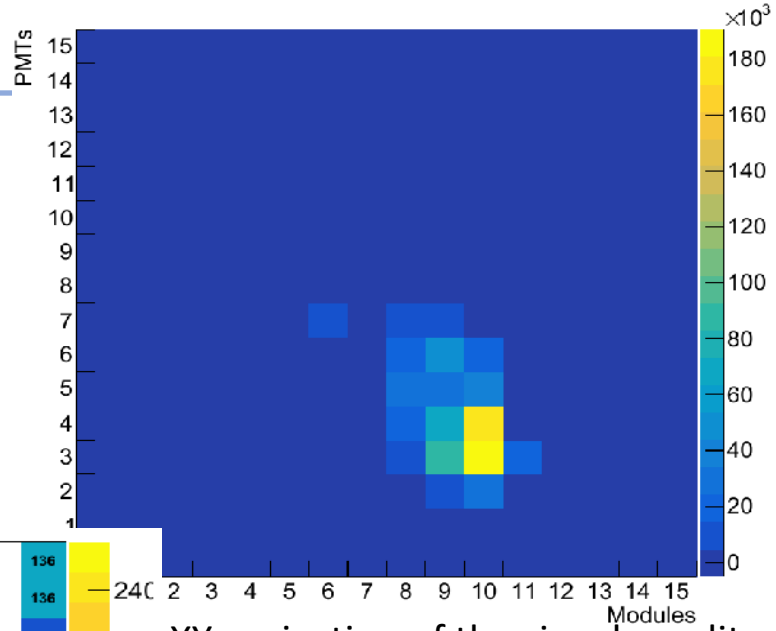
Event №160905-129



Time dependence of integral amplitude of the signal

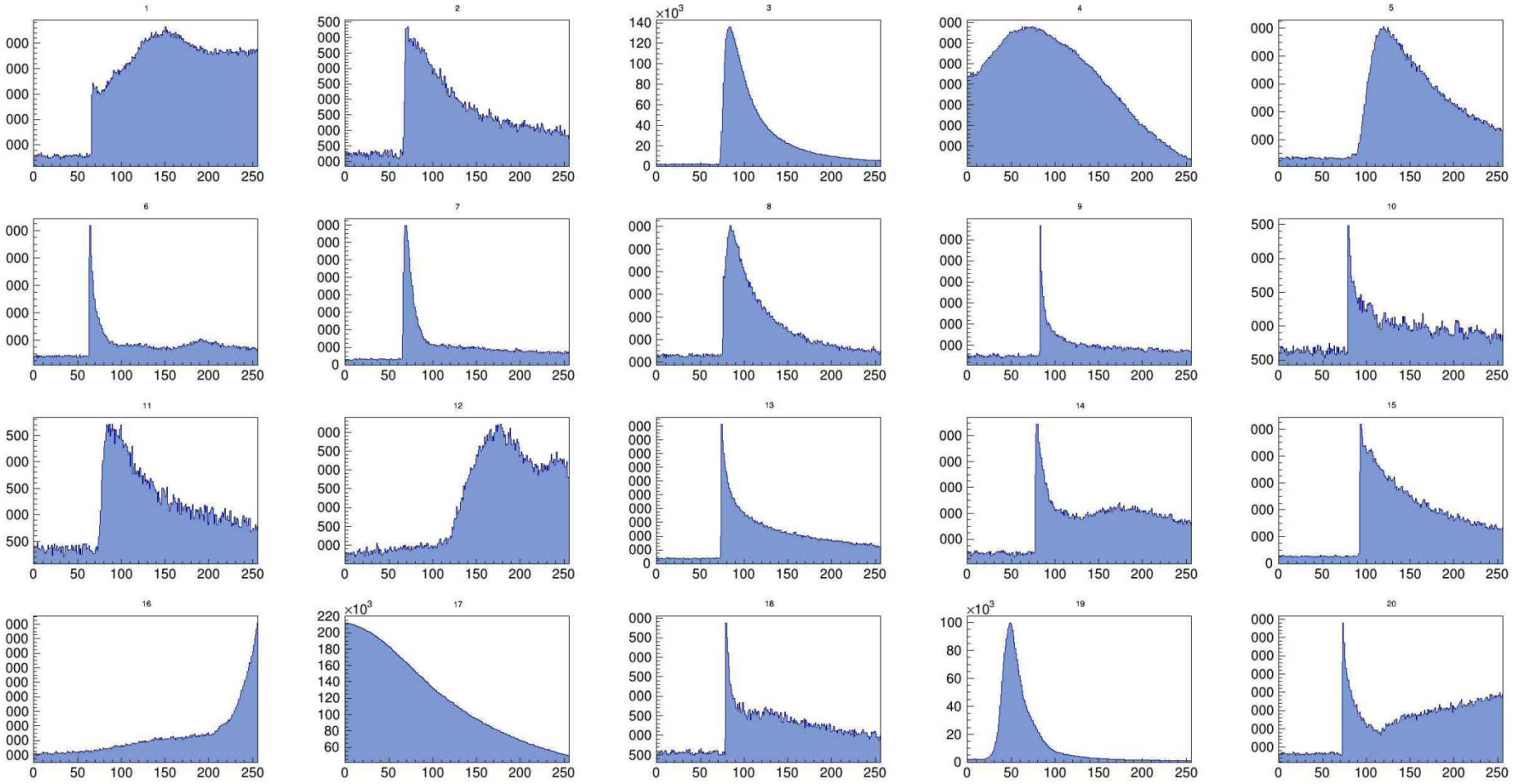


The movement of the signal along the photodetector plane, after cutting off the first peak



XY projection of the signal amplitude onto the photodetector matrix with a threshold of 3 RMS

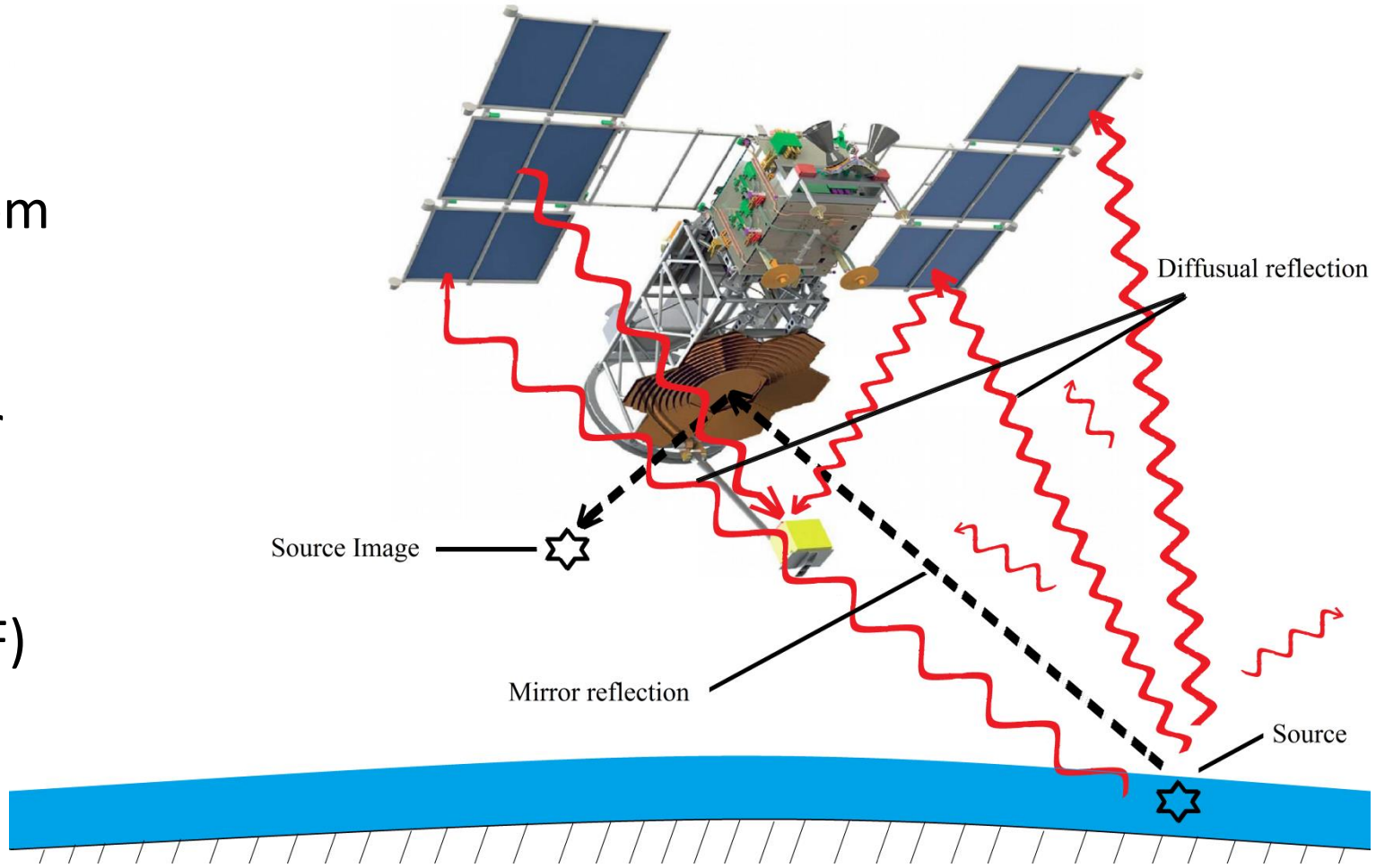
Time dependence of the signal integral amplitude for 20 anomalous events



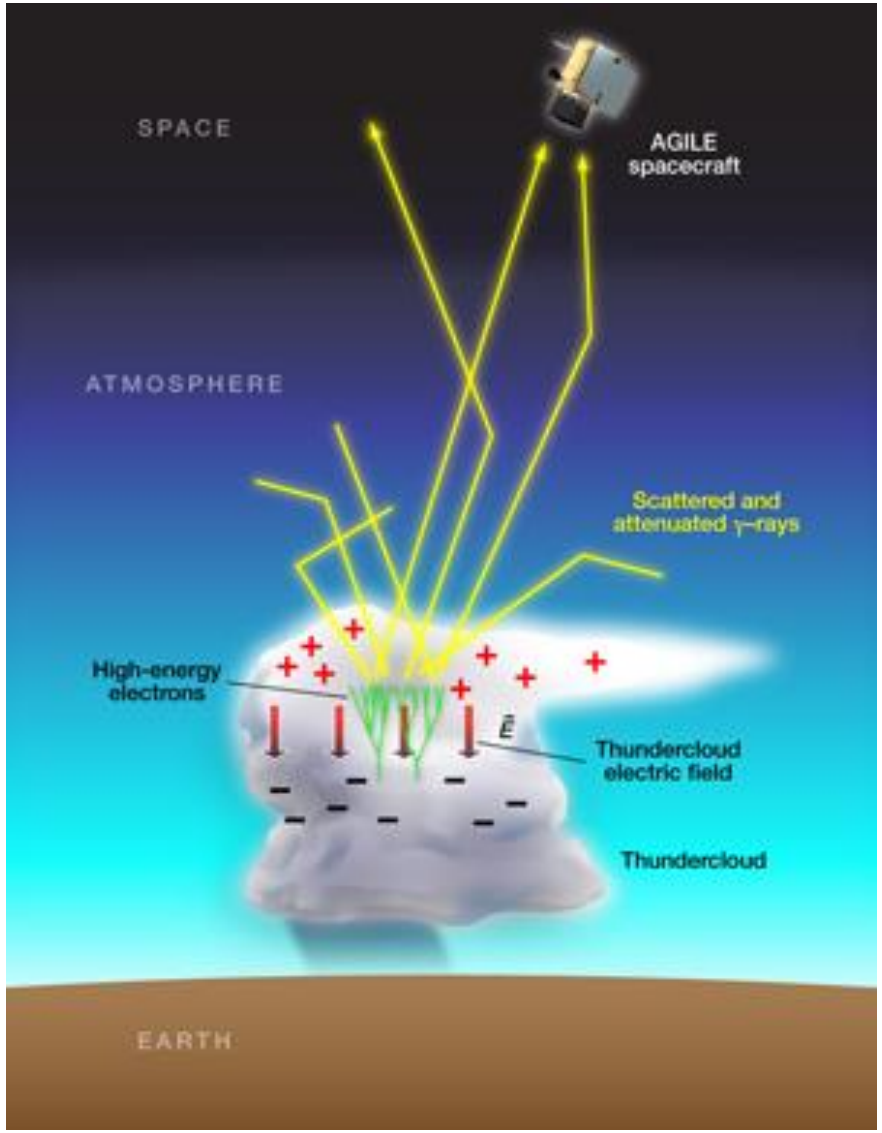
Time dependence of integral amplitude of the signal for another 20 anomalous events

Possible interpretation

- Gamma Ray Burst(GRB)
- Diffuse reflection of lightning from solar panels and mirror:
    1) Upward-going EAS (only for hybrid and combined)
    2) Terrestial gamma flash (TGF)



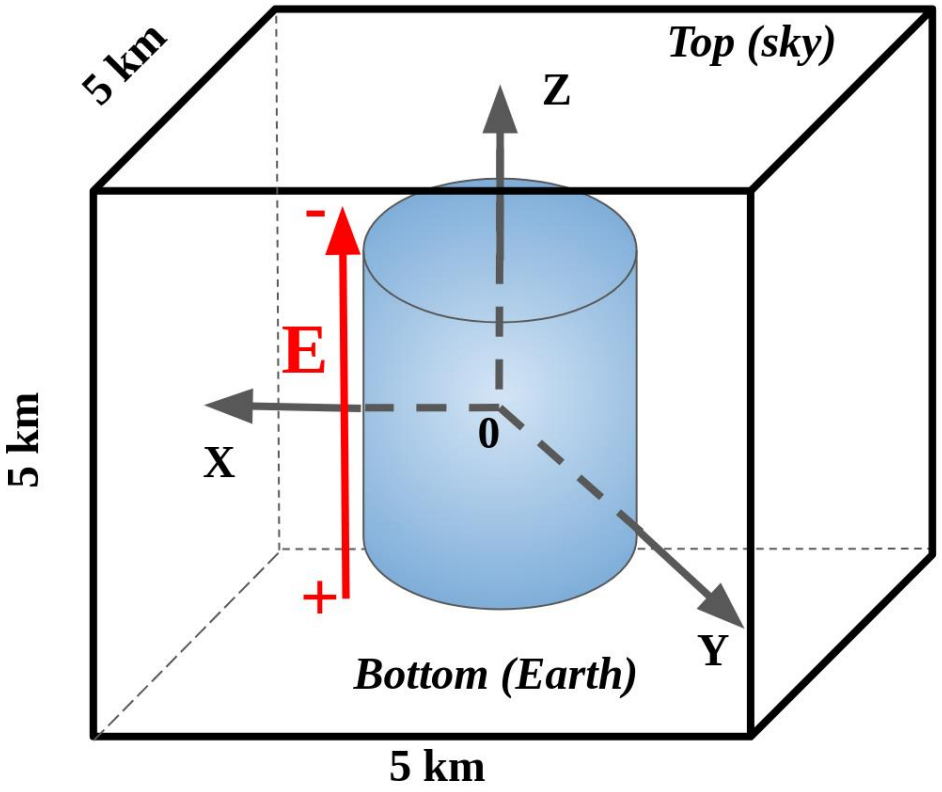
Terrestial gamma flash



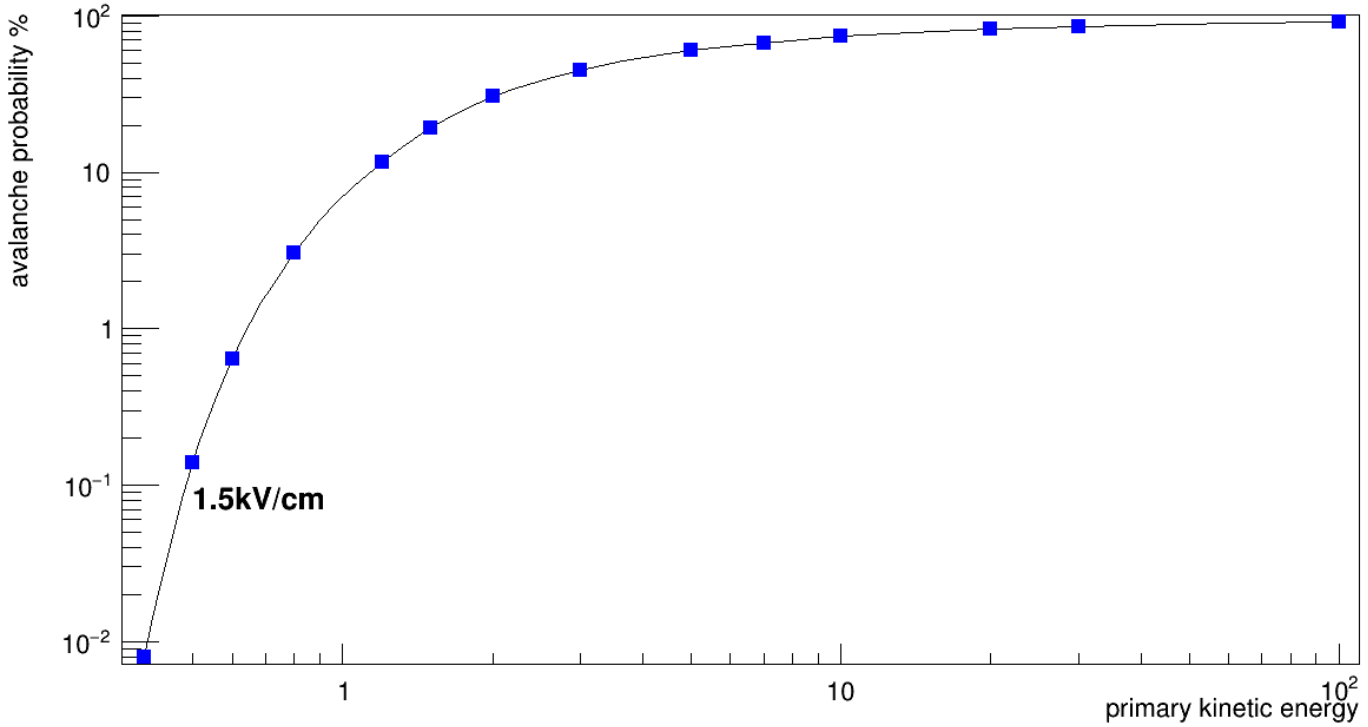
Terrestrial gamma-ray flashes (TGFs) are atmospheric gamma—ray bursts, which are showers of photons and electrons with energy up to several tens of MeV, formed in the atmosphere during the development of a relativistic avalanche of escaping electrons RREA (Relativistic Runaway Electron Avalanche).

Marisaldi, Martino et al. (2015). Enhanced detection of terrestrial gamma-ray ashes by AGILE". In: Geophysical research letters 42.21, pp. 9481-9487.

Simulation of TGF

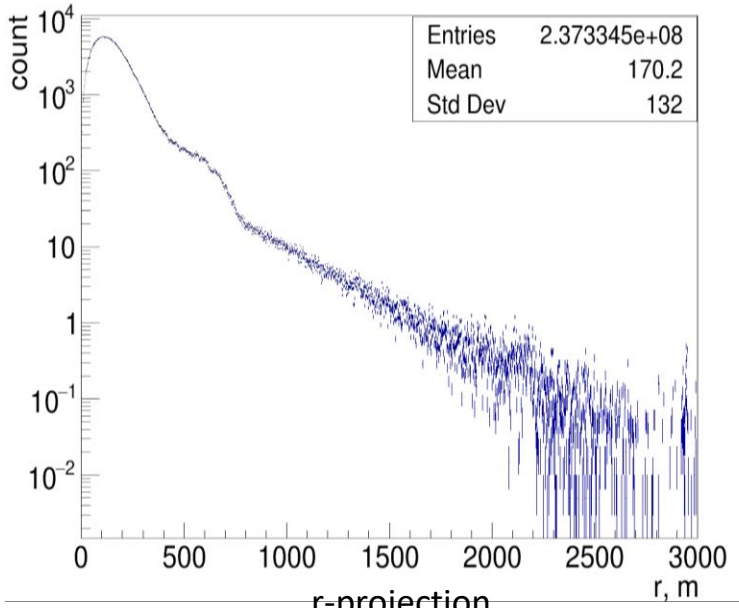


Schematic view of cloud geometry in GEANT4

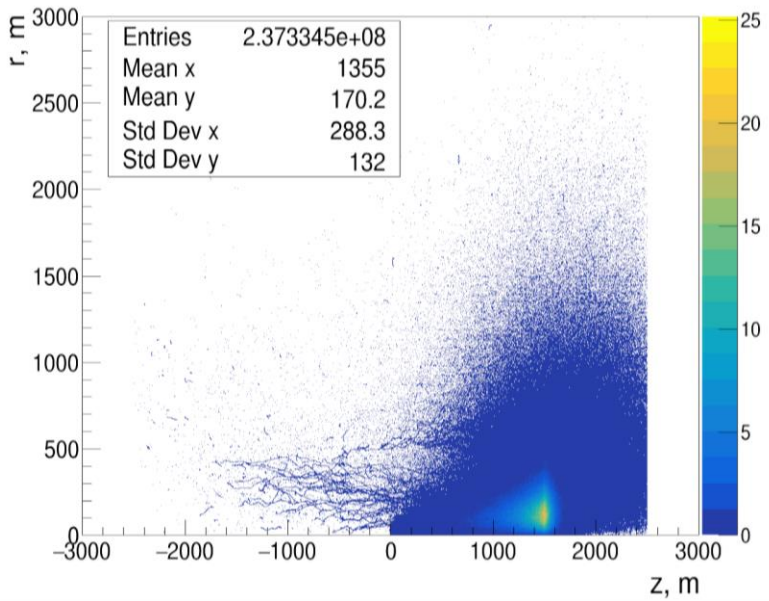


The probability of shower development at a field value of 1.5 kV/cm, with different energies of the primary electron

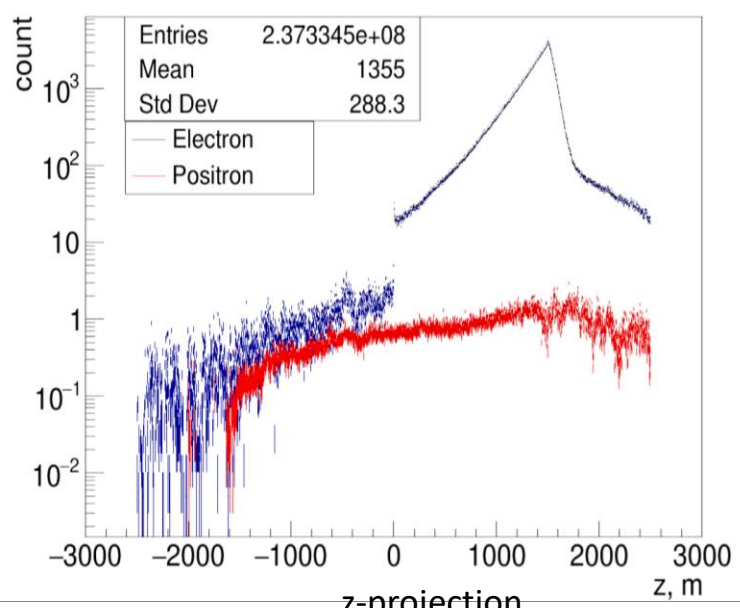
Simulation of TGF



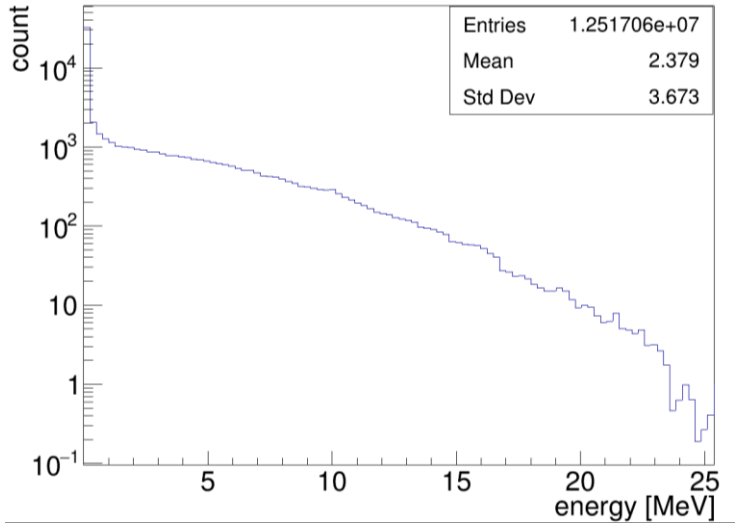
r-projection



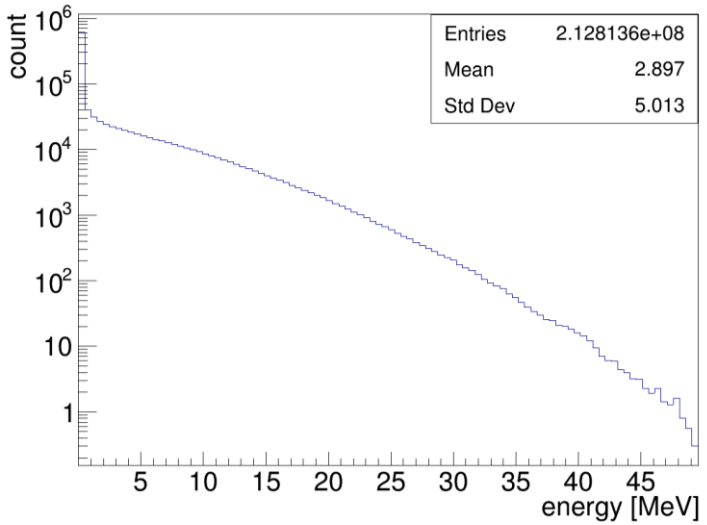
2D distributions of r,z-coordinates of secondary electrons from the initial electron with energy of 10 MeV for fields of +1.5 kV/cm



z-projection



Energy distributions of secondary electrons in a shower initiated by a primary electron with an energy of 10 MeV at a field of -1.5 kV/cm (left) and a field of +1.5 kV/cm (right)



Conclusions

- During its operation, the TUS detector registered about 200,000 events in EAS mode.
- 46 anomalous events were detected, 5 of which are hybrid.
- The probable nature of such atmospheric events are lightning discharges, diffuse reflected from the satellite's solar panels and mirror.
- In GEANT-4, a software package for simulation TGF and TGE events in a thundercloud is currently under development and preliminary results are presented.

Thank you for your attention!

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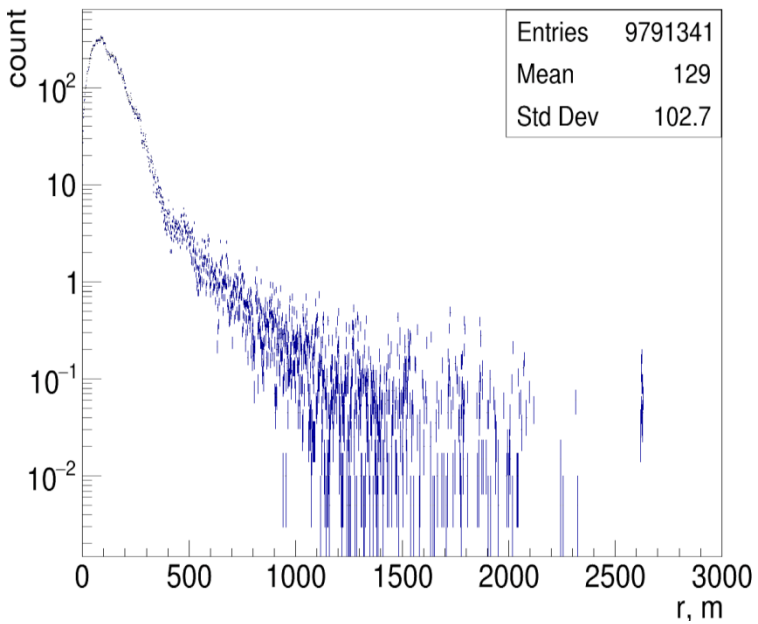
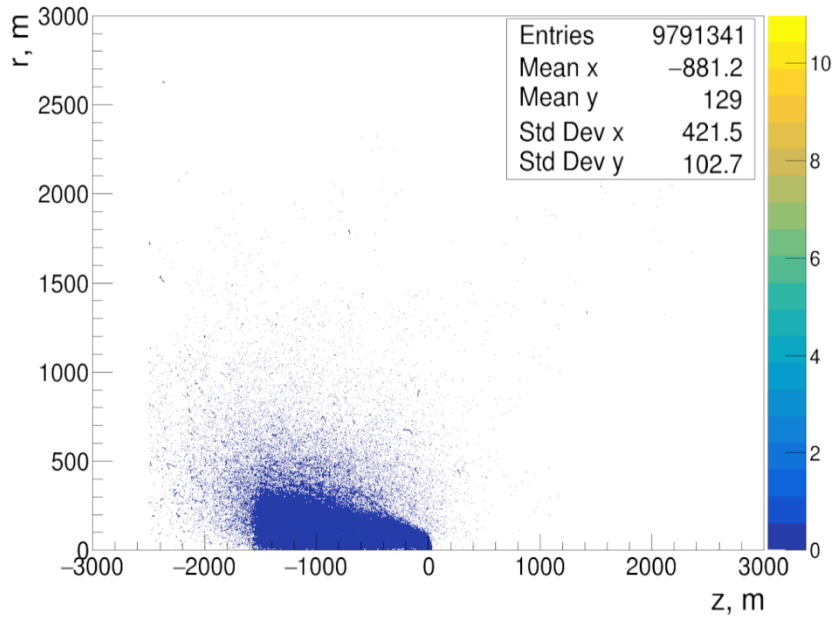
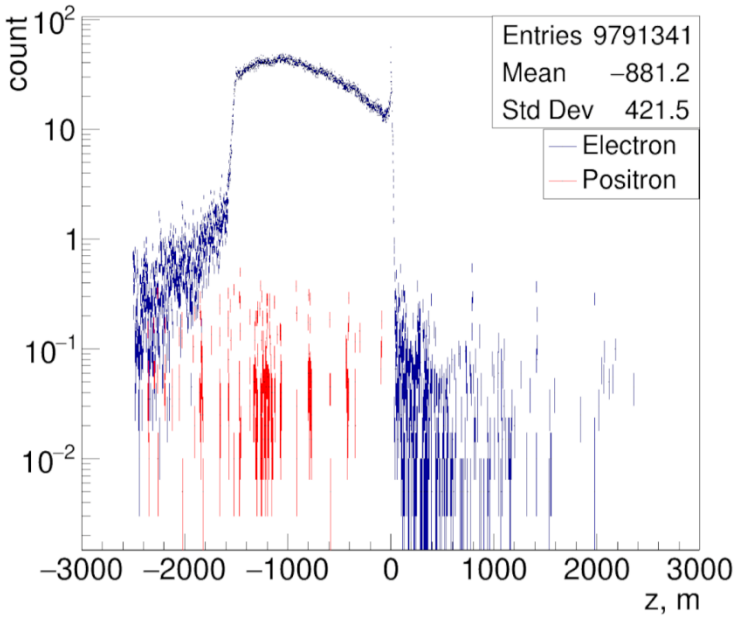
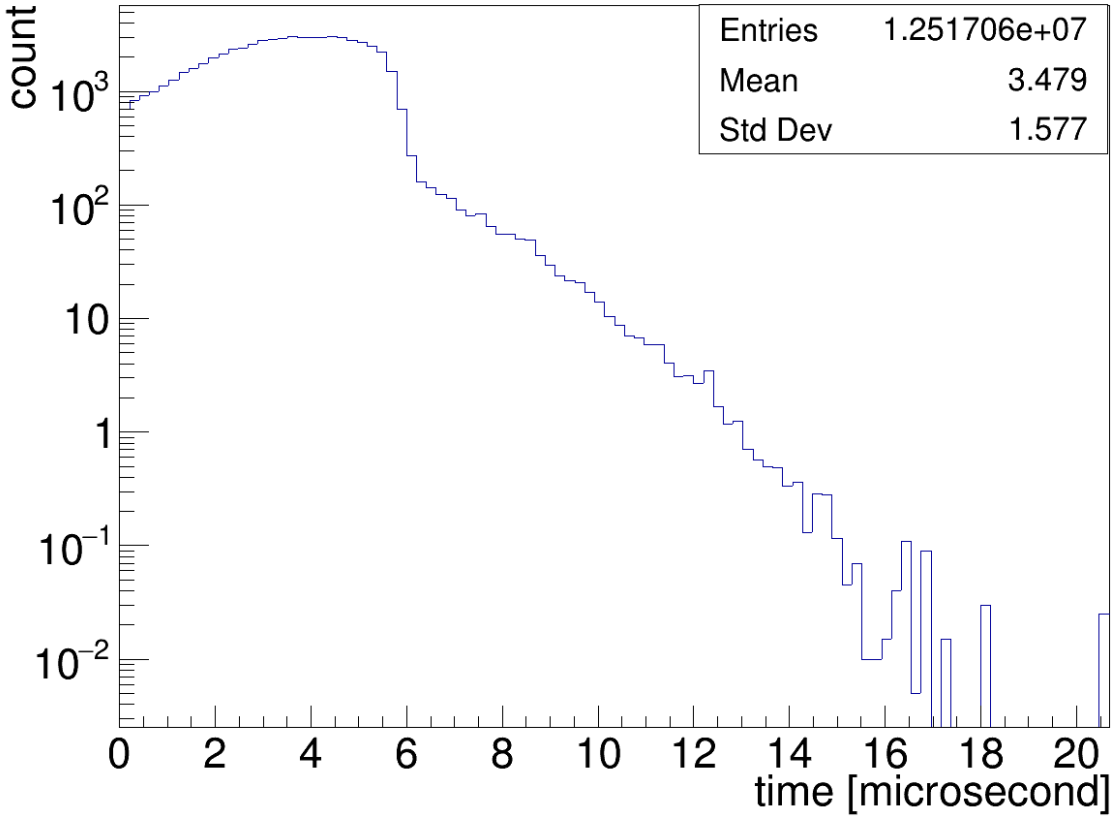
Backup slides

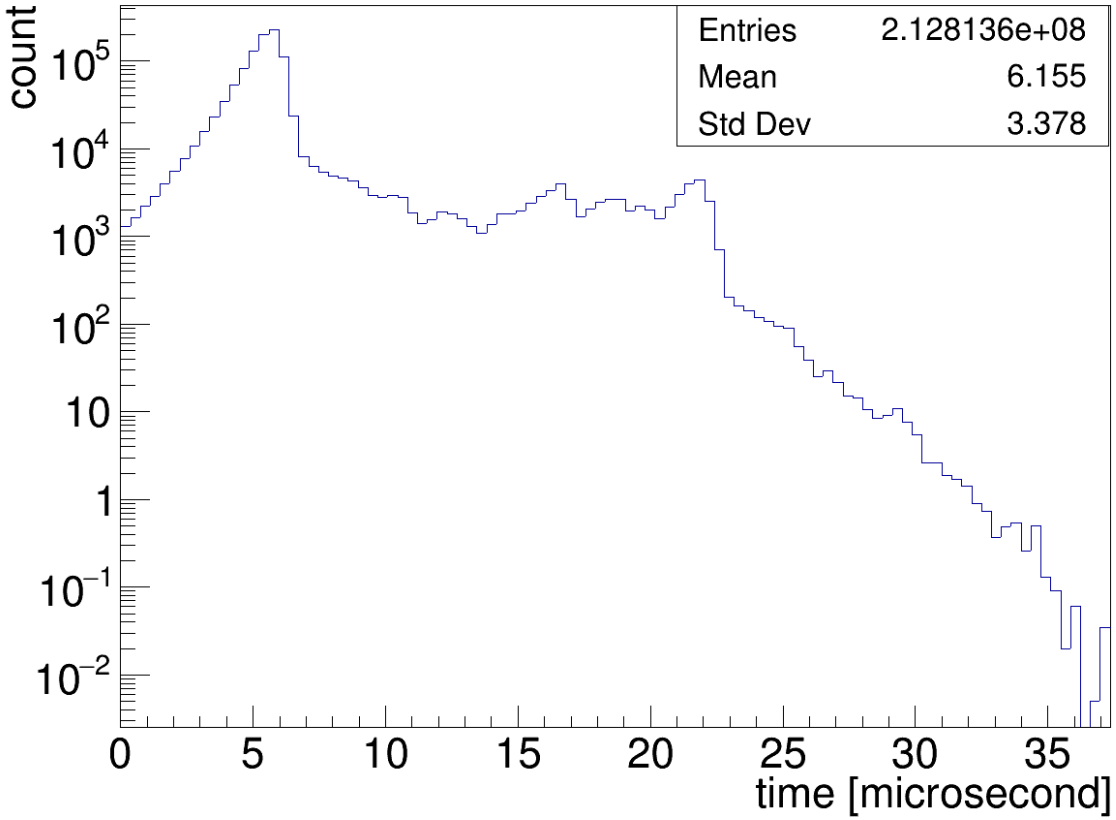






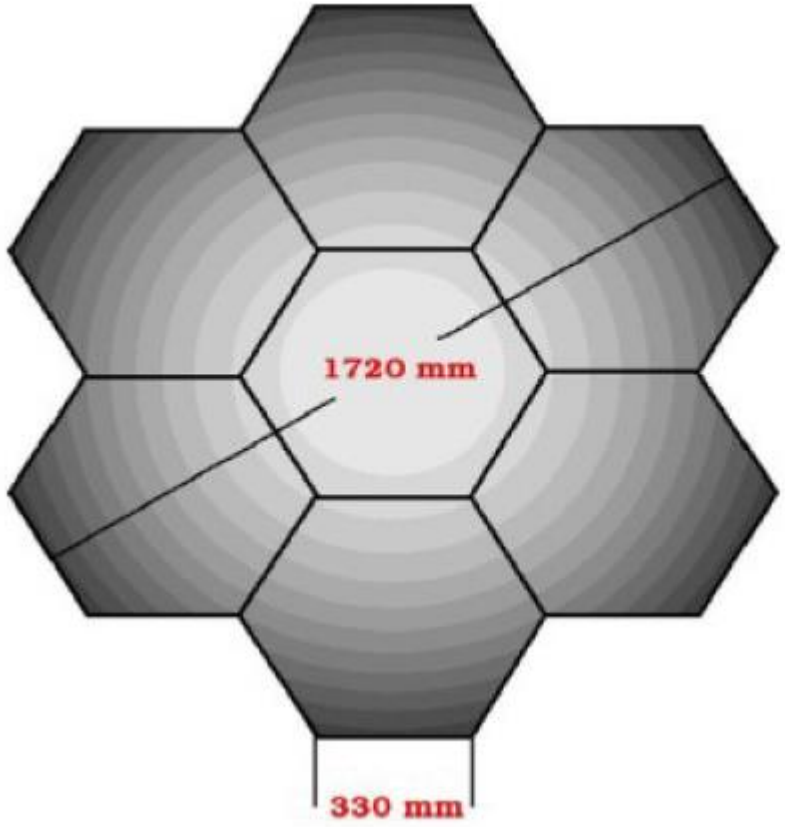
В центре: 2Д-распределения r,z-координат вторичных электронов от первоначального электрона с энергией 10 МэВ для полей -1,5 кВ/см на высоте ТШВКС. Слева: r-проекция, справа — z-проекция.



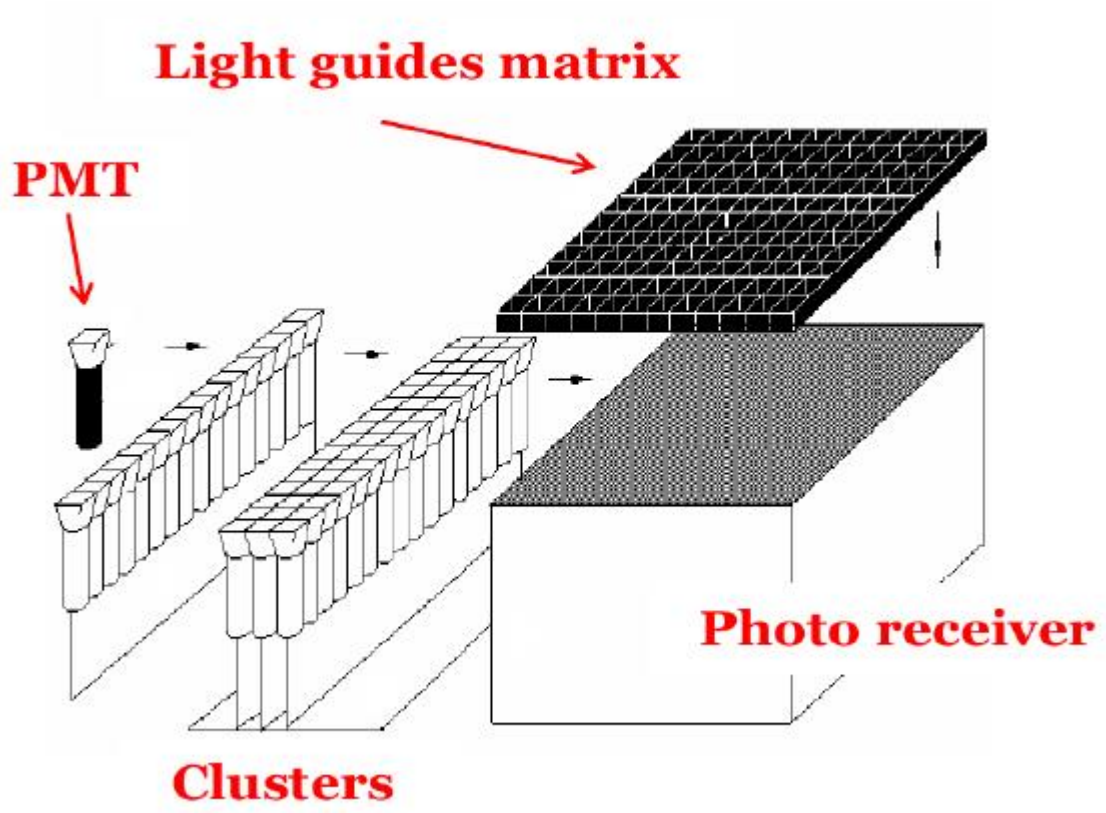


Распределение по времени генерации вторичного электрона в ливне, инициированном первичным электроном с энергией 5 МэВ при поле -1.5 кВ/см (слева) и полем +1.5 кв/см (справа).

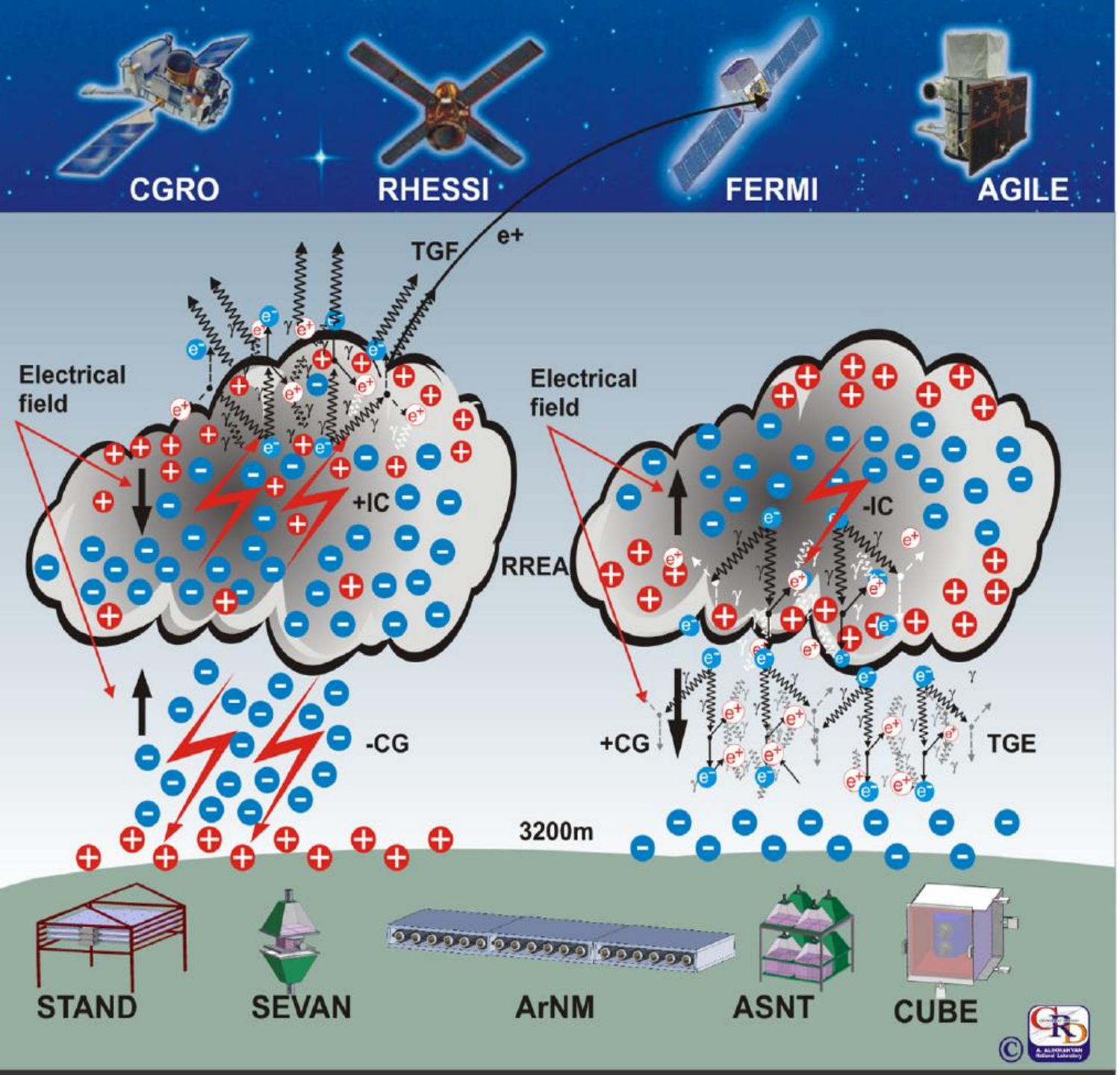
Fresnel mirror and photodetector



Fresnel mirror

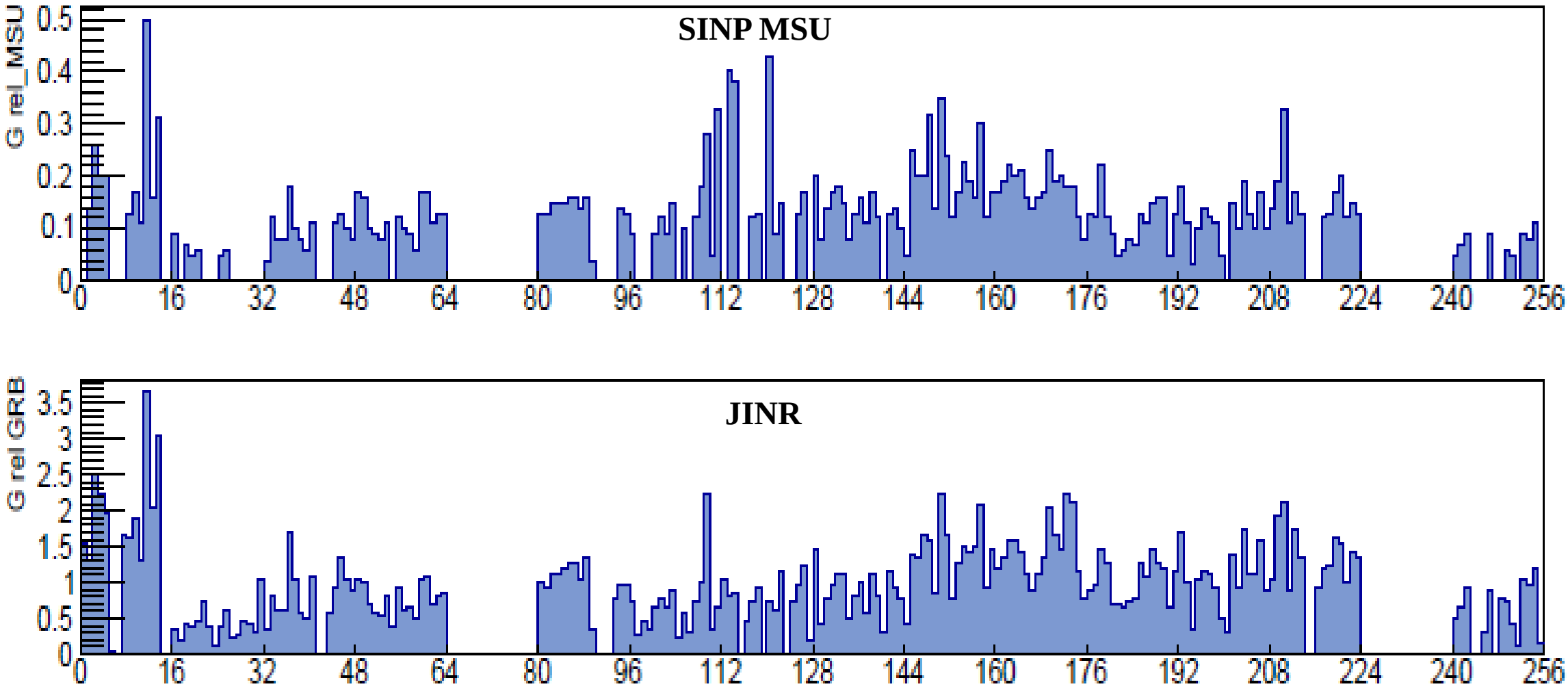


Photodetector

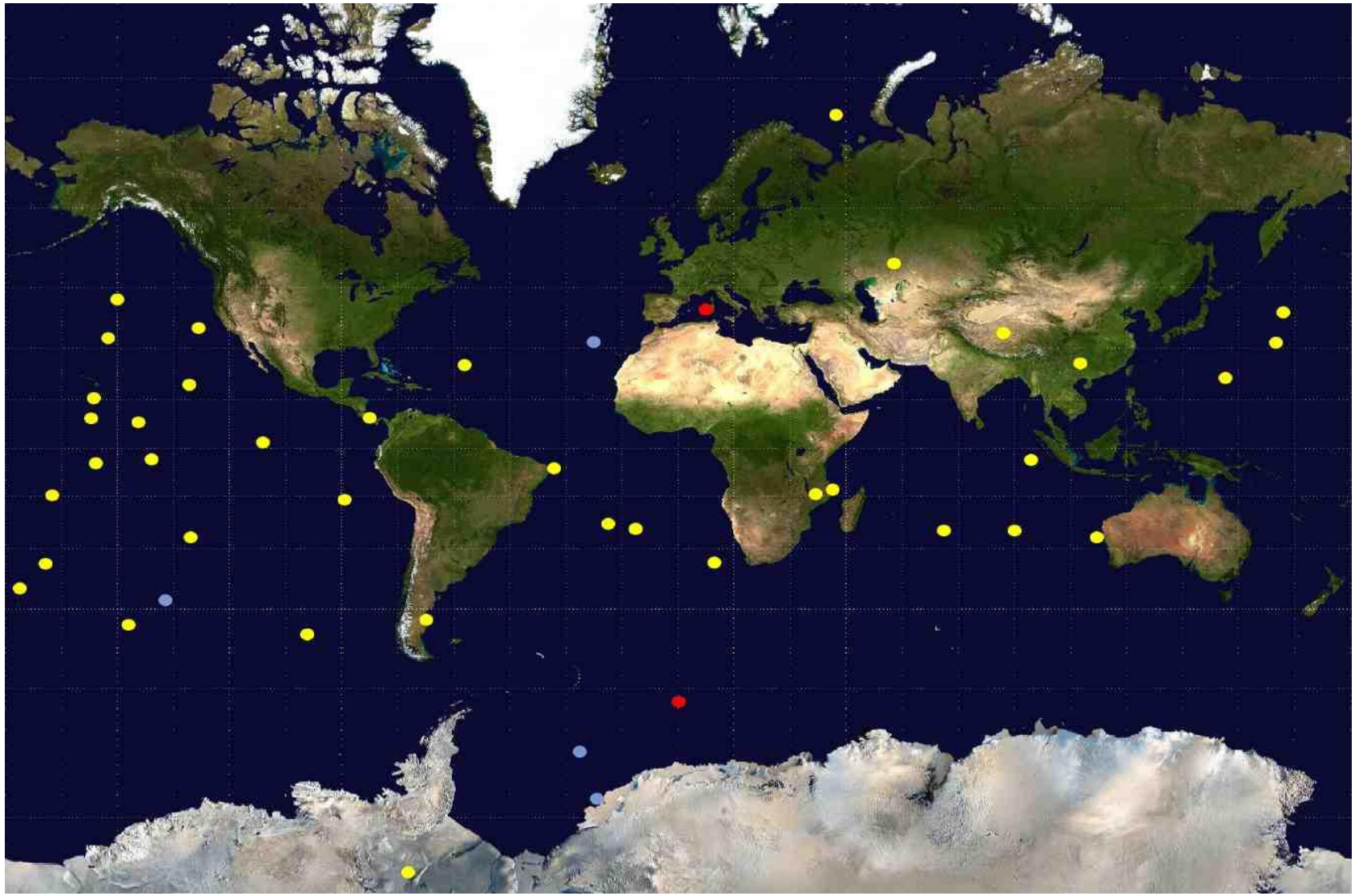


Terrestrial gamma-ray flashes (TGFs)—короткая гамма вспышка, рожденная в атмосфере.

PHYSICAL REVIEW D 83, 062001 (2011)
Particle bursts from thunderclouds: Natural particle accelerators above our heads
Ashot Chilingarian, Gagik Hovsepyan, and Armen Hovhannisyan

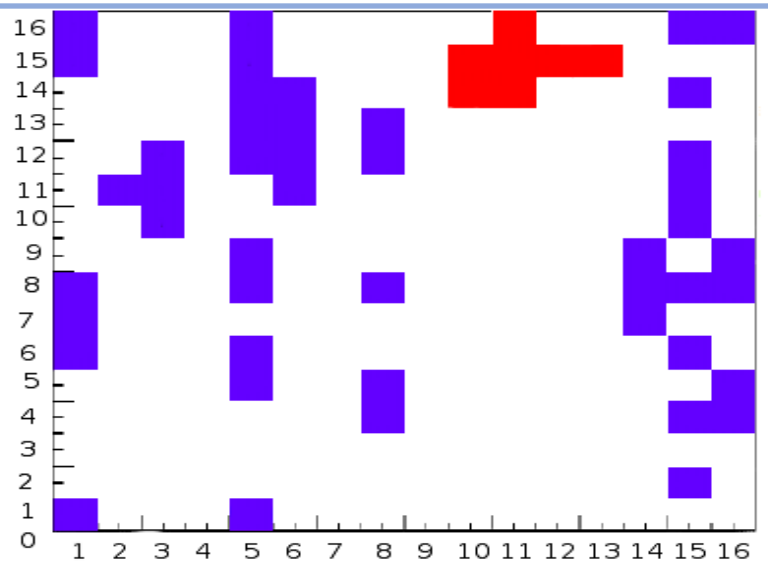

SINP MSU
G rel_MSU
0
0.1
0.2
0.3
0.4
0.5
0
16
32
48
64
80
96
112
128
144
160
176
192
208
224
240
256
JINR
G rel GRB
0
0.5
1
1.5
2
2.5
3
3.5
0
16
32
48
64
80
96
112
128
144
160
176
192
208
224
240
256

Map of anomalous events

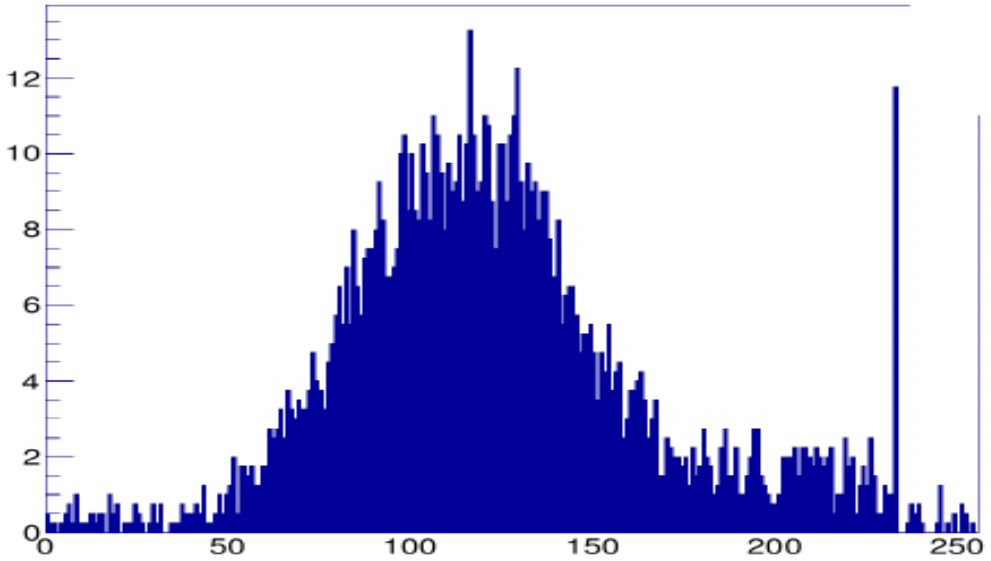


- anomalous
- combined
- hybrid.

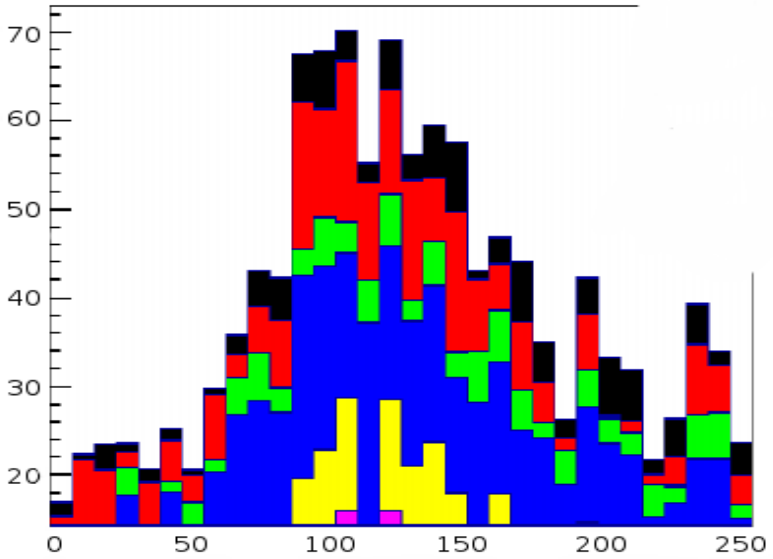
Шалоподобные события



Изображение события со сработавшими пикселями и не работающими(синие)



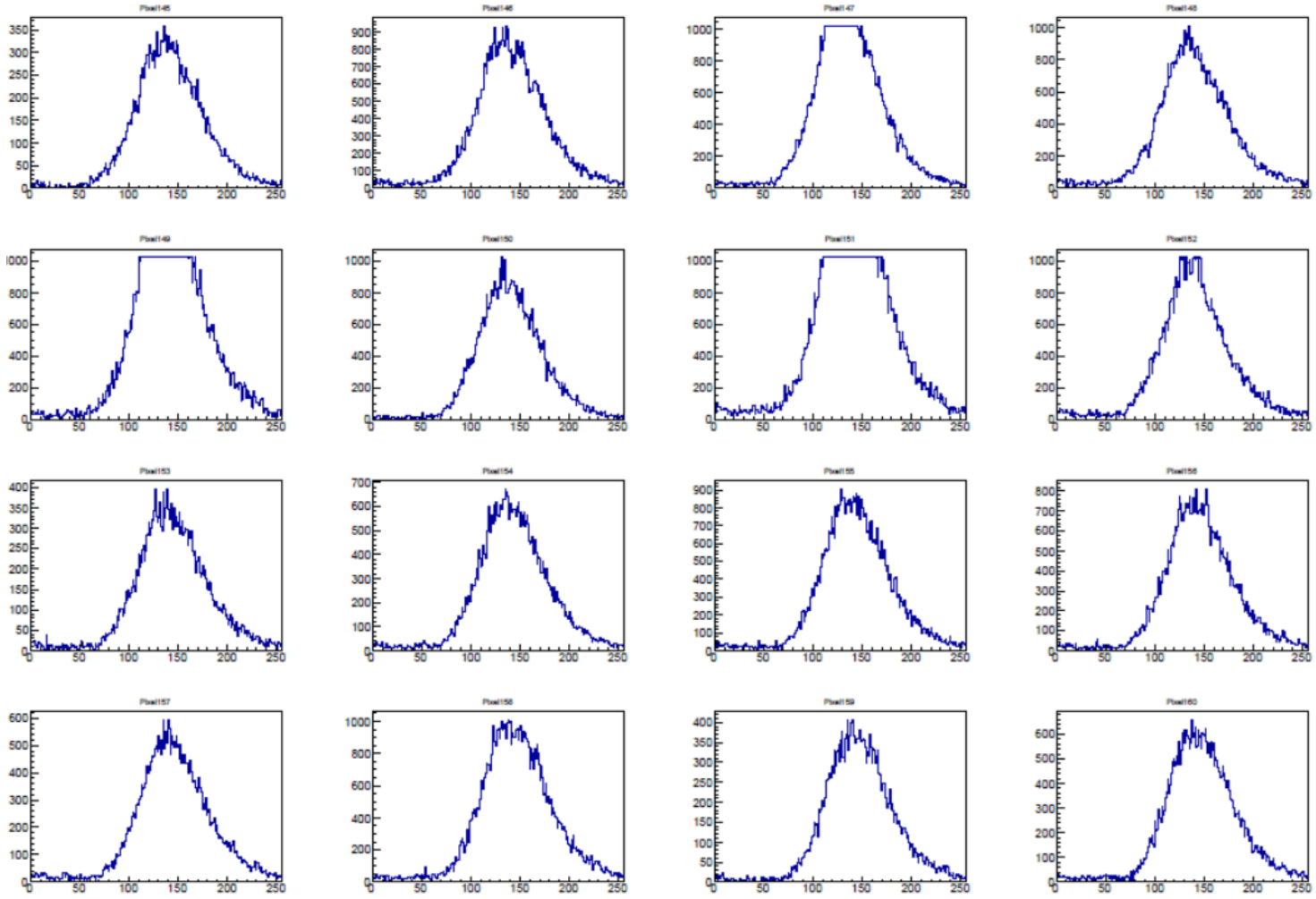
ESAF MC event. E = 10^{20} эВ, θ = 60°



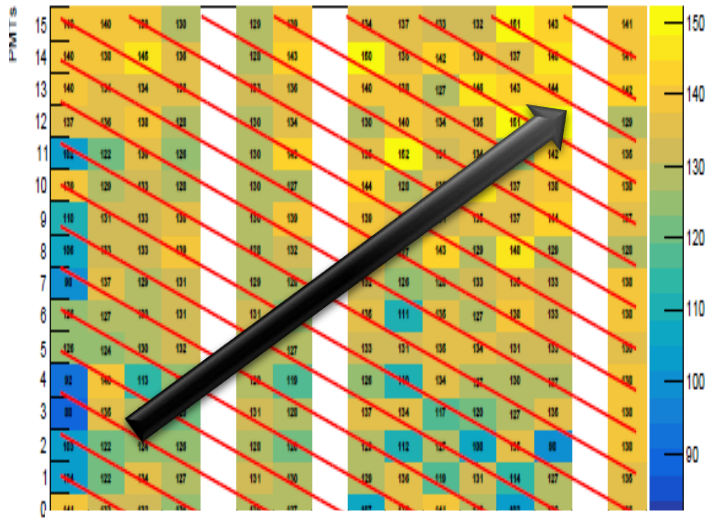
Пример шалоподобного события

Георграфическое распределение шалоподобных событий.

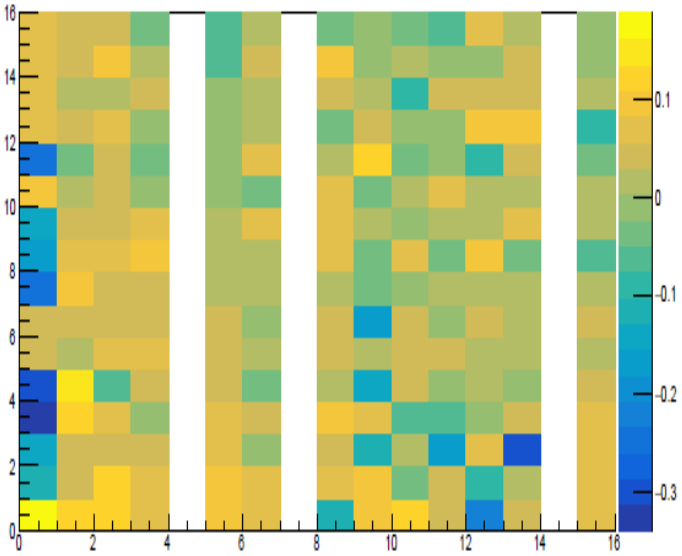
Anomalous event №170818-072



Time dependence of amplitude in 10th module

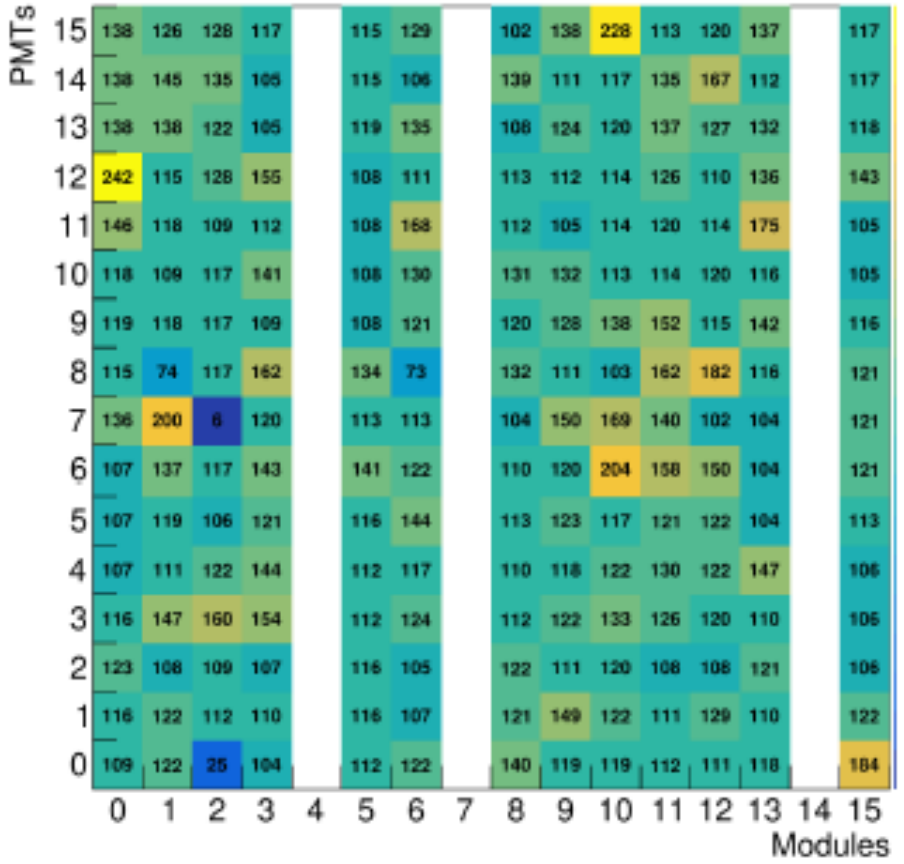


$$z = p_0 + p_1 \cdot x + p_2 \cdot y$$

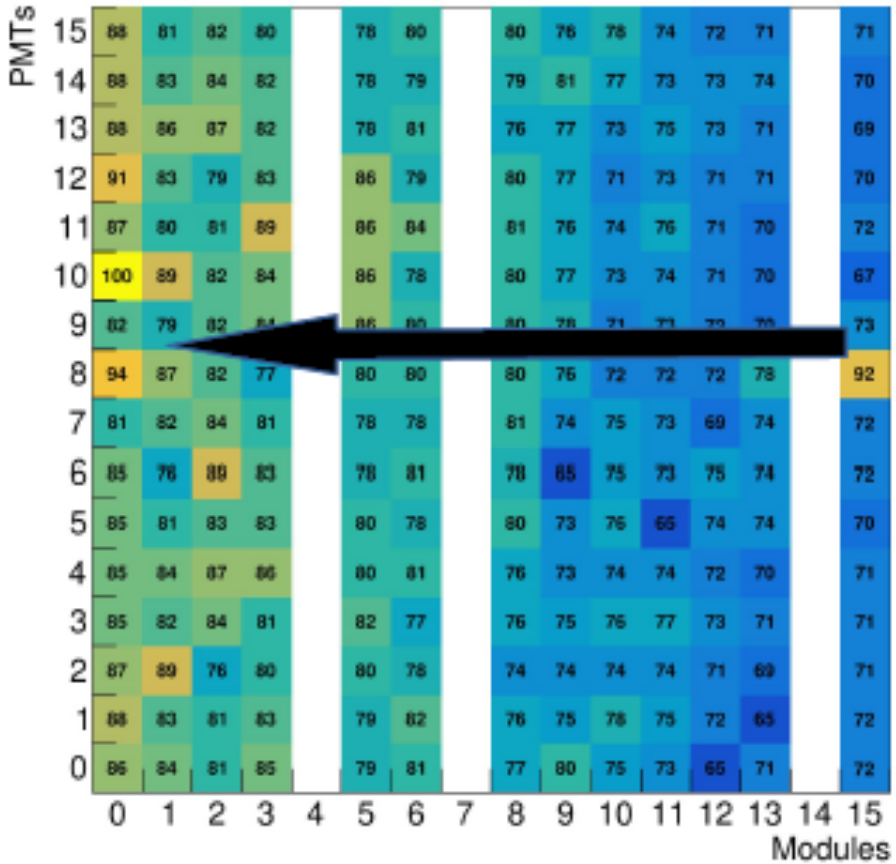


Movement in anomalous events

Event without movement in plane of the photodetector

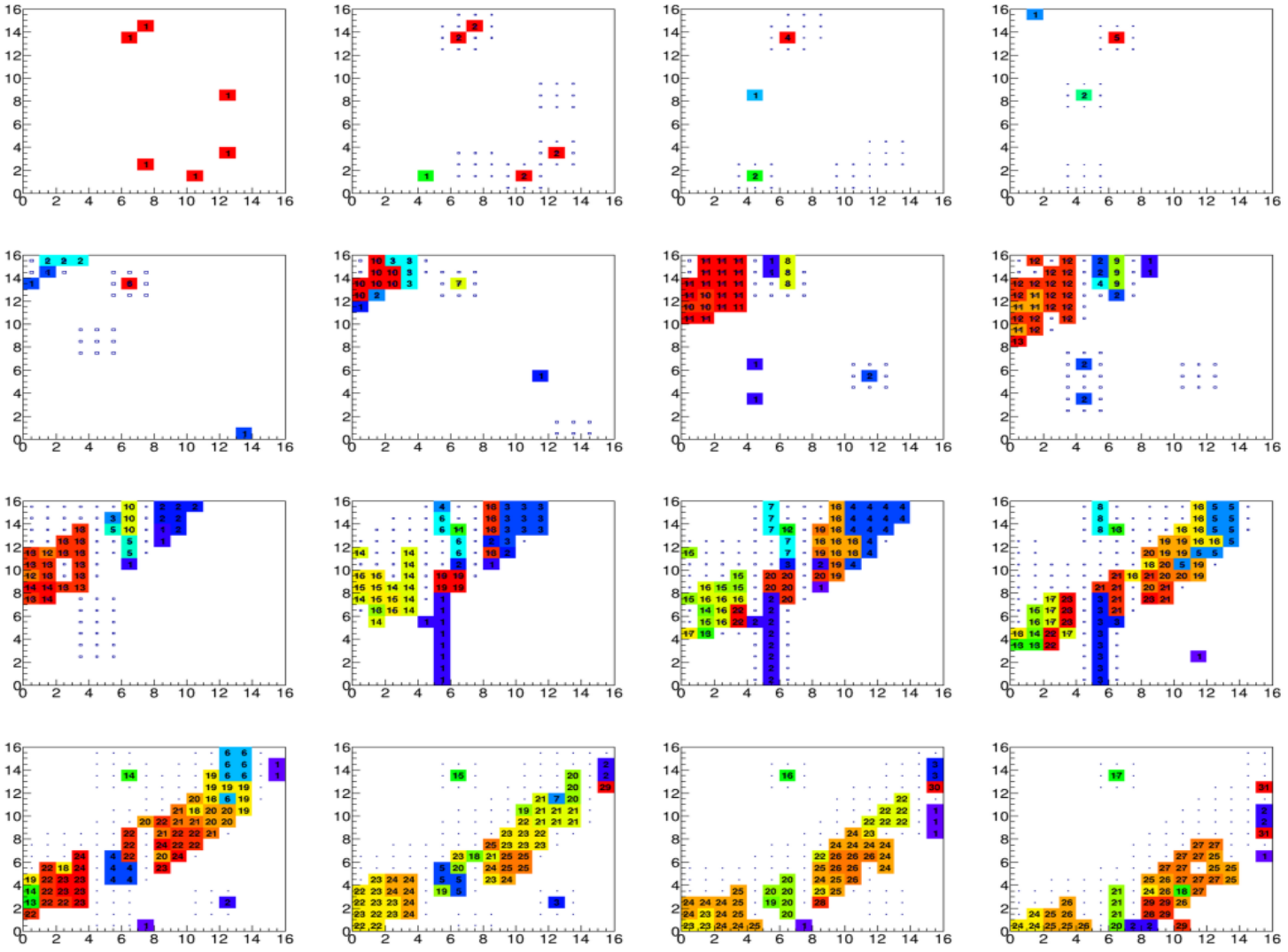


Event with movement in plane of the photodetector



2D Distribution of the transit times of the signal amplitude maxima on the photodetector matrix.
The arrow indicates the direction of movement of the signal

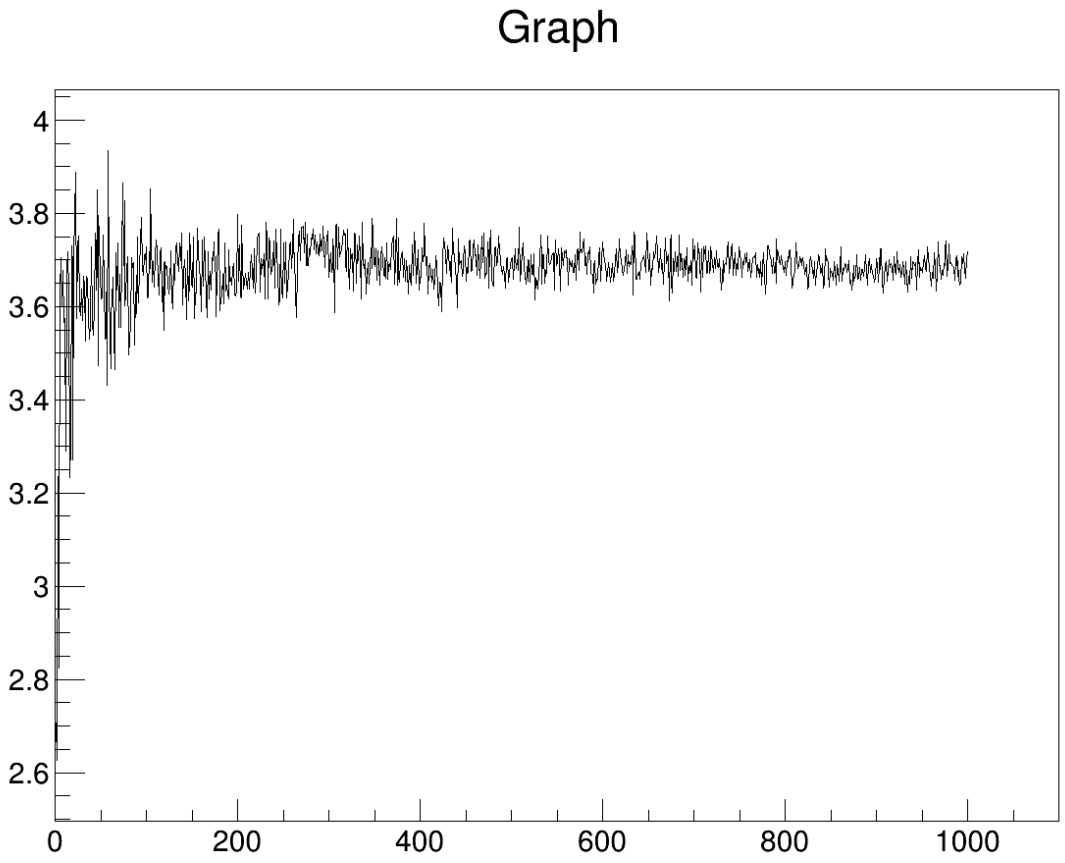
ELVE



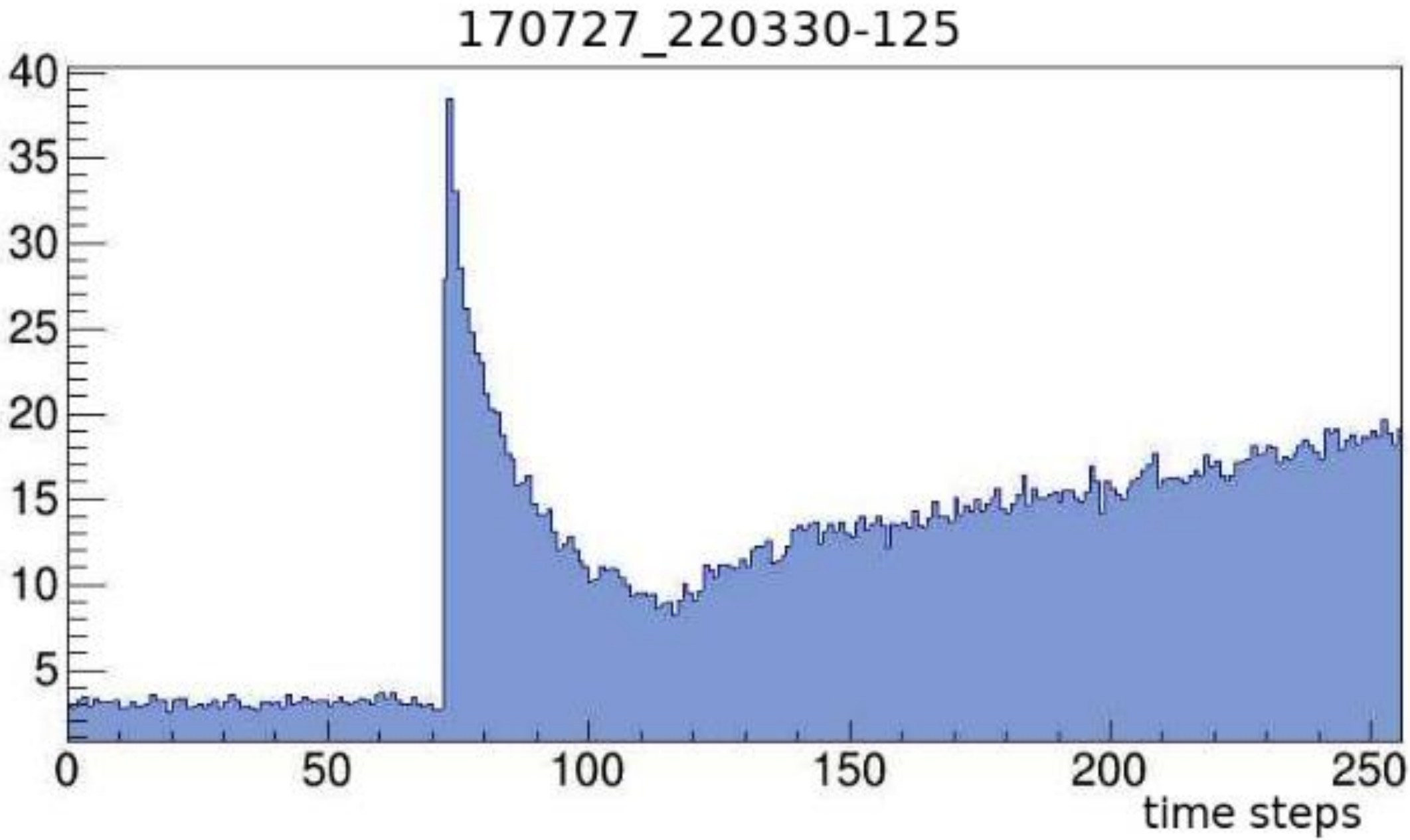
Event map-plot of the ELVE event

Количество фотонов от восходящего ШАЛ

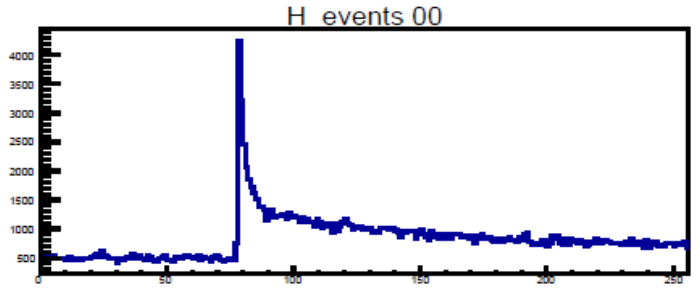
Была взята плоскость, радиусом 1 км. При прохождении через нее черенковских фотонов происходила запись. На данном слайде представлены графики распределения по радиусу нормированное на квадратный метр для двух случаев : Энергия первоначального протона 1 ТэВ и 100 ТэВ.

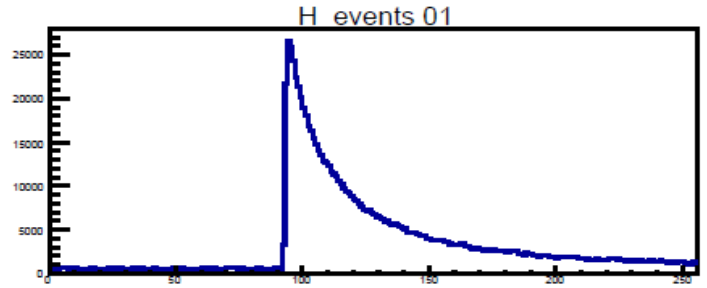


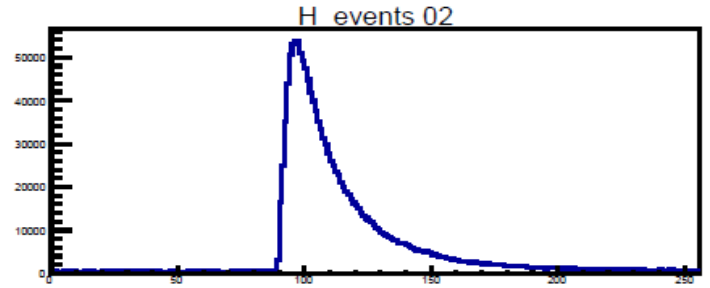
Integral histogram of the time dependence amplitude on time of combined event

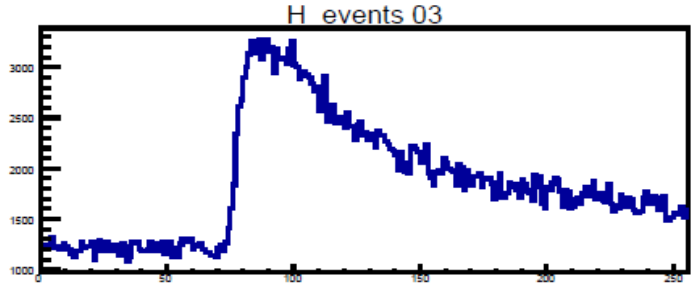


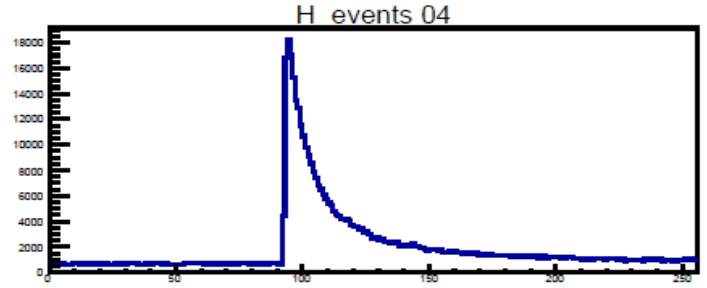
The time dependence of the total signal amplitude for several anomalous events

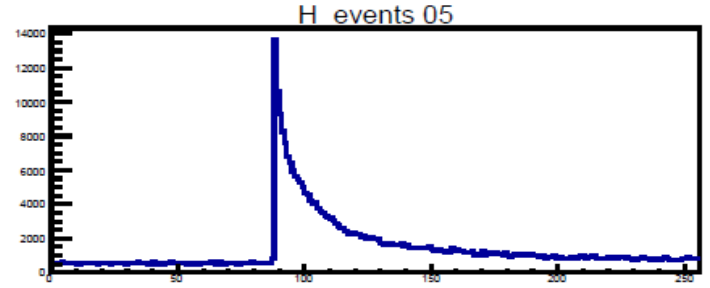


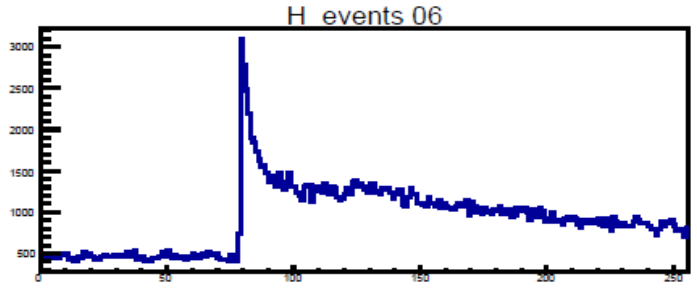


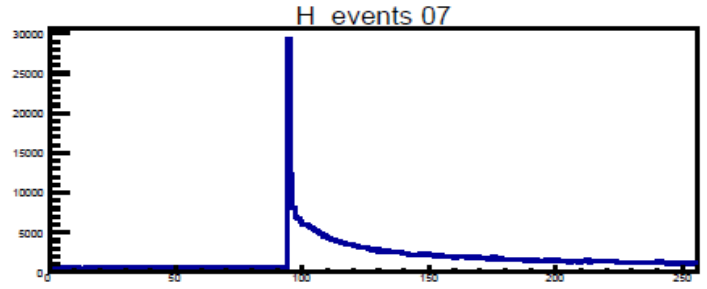


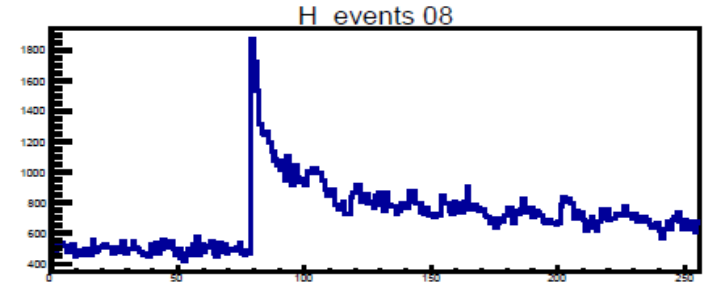


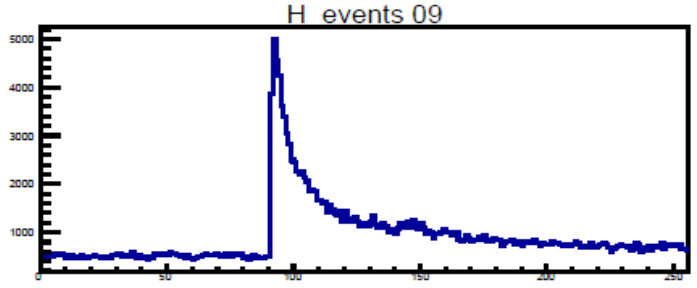


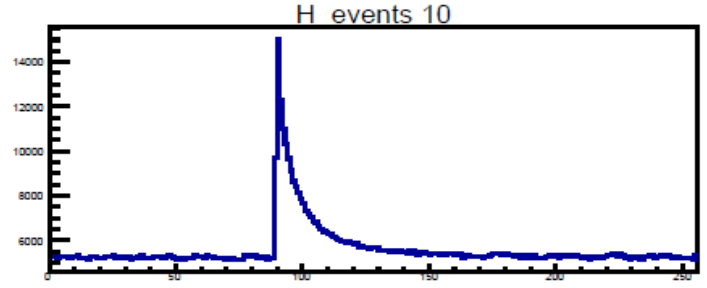


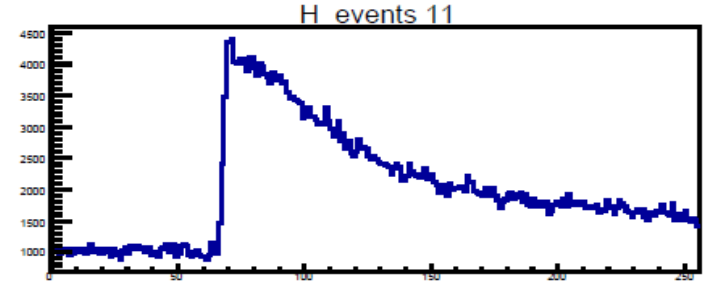












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