# Spatial and Temporal Characteristics of EAS with Delayed Particles

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HORIZON-T COLLABORATION

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# Horizon-T Group

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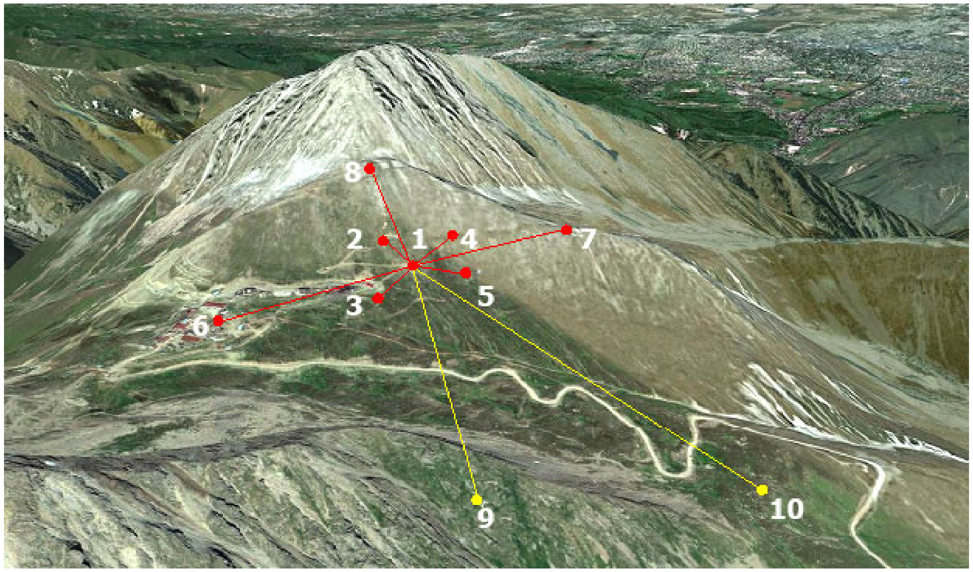
# Horizon-10T (H10T) Detector System [1, 2, 3]




| Point name | Center | Right | Kurashkin | Left | Bottom | Yastrebov | Stone Flower | Upper | East 600m | Bunker |
|---|---|---|---|---|---|---|---|---|---|---|
| Point # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

An innovative detector system

- pulse shape -> disk width information
- up to 2 ns resolution

EAS $E_0 > 10^{16}$ eV ; Zenith angles from 0º to 85º.

At Tien Shan high-altitude Science Station ~3340 meters above the sea level

**10** charged particle detection points, separated by the distance up to 1.3 kilometer

Hardware trigger points 3+1 or 3+4, any offline combination

Optical detector subsystem

- to view the Vavilov-Cherenkov light from the EAS

# H10T Detector System

Technical characteristics of H10T are below in two tables:

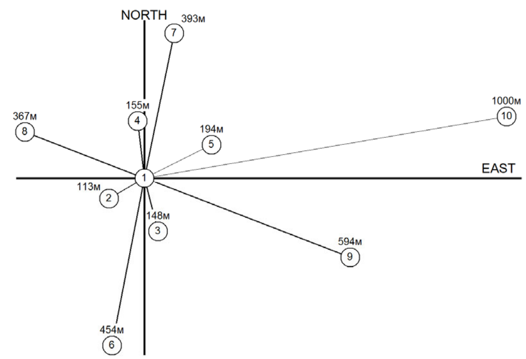
Table 1: Distance R of each detection point from center (point 1).

| Point # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| R, m | 0 | 133 | 148 | 155 | 194 | 454 | 393 | 367 | 594 | 1000 |

Table 2: Detector system acceptance and event rate.

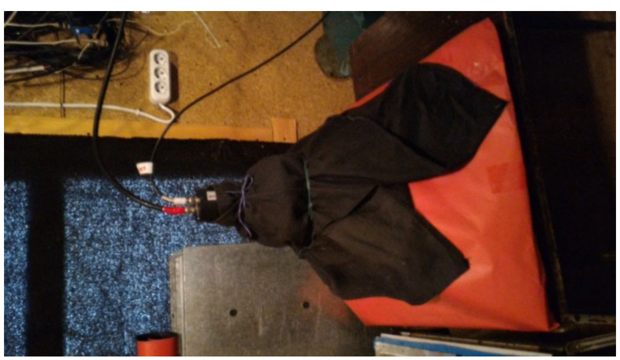
| $E_0$ [eV] | $10^{16}$ | $2 \cdot 10^{16}$ | $5 \cdot 10^{16}$ | $10^{17}$ | $2 \cdot 10^{17}$ | $10^{18}$ |
|---|---|---|---|---|---|---|
| Γ [$km^2$ sr] | 0.38 | 0.72 | 0.97 | 1.52 | 2.72 | 6.31 |
| N/t [event/h] | 25.60 | 7.98 | 2.25 | 1.04 | 0.52 | 0.06 |

# H10T charged particle detectors



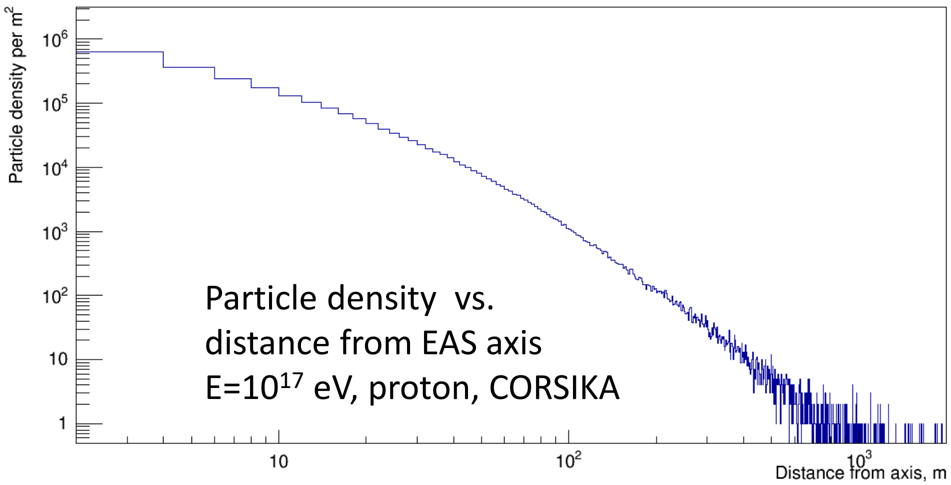

Scintillator [3]
- ~7 ns pulse rise time

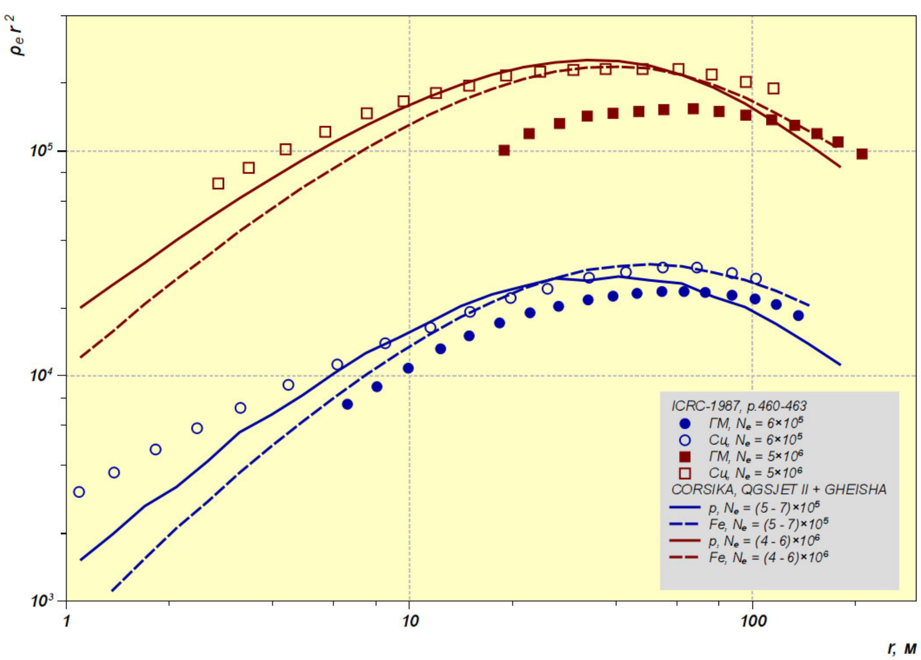
Glass [4]
- ~2.1 ns pulse rise time

- R7723 Hamamtsu [5] PMT (1.2 ns resolution) at points 1-8
- H6527 Hamamatsu PMT at points 9-10
- 500 MHz digitization CAEN [6] DT5730 ADC

# EAS Representation as Electron-Hardon Shower [2,7]




CORSIKA [8] simulation software is based on our current understanding of HEP, thus simulating a '**standard**' shower.

At observation level, such EAS has a single disk with particle density ~$1/r^2$ from the axis

Data from experiment 'Hadron'

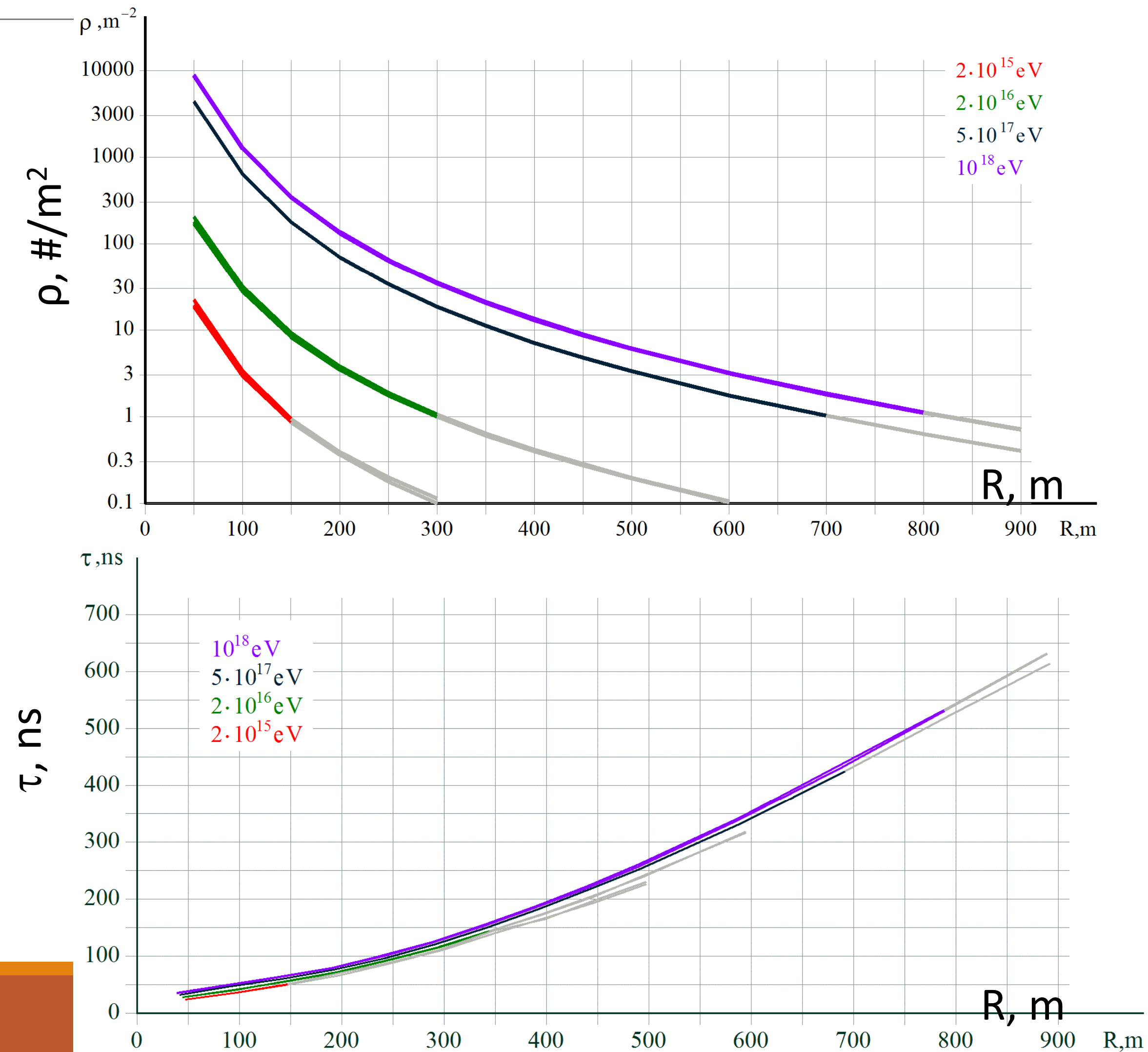
- Adamov D.S. et al. 'Phenomenological Characteristics of EAS with N(E)=2*10**5-2*10**7 obtained by the Modern Tien-Shan Installation "Hadron"', Proceedings of the 20th International Cosmic Ray Conference Moscow, Volume 5, p.460, 1987. Code: 1987ICRC....5..460A

# EAS particle density and disk width from CORSIKA

Particle density (top plot) and disk width (bottom plot) are given for EAS with primary proton energy of:

- $2\times10^{15}$ eV (in red)
- $2\times10^{16}$ eV (in green)
- $5\times10^{17}$ eV (in black)
- $10^{18}$ eV (in violet)

Gray lines are were particle density is < 1 particle/m$^2$



# Temporal distribution of particles within disk from CORSIKA

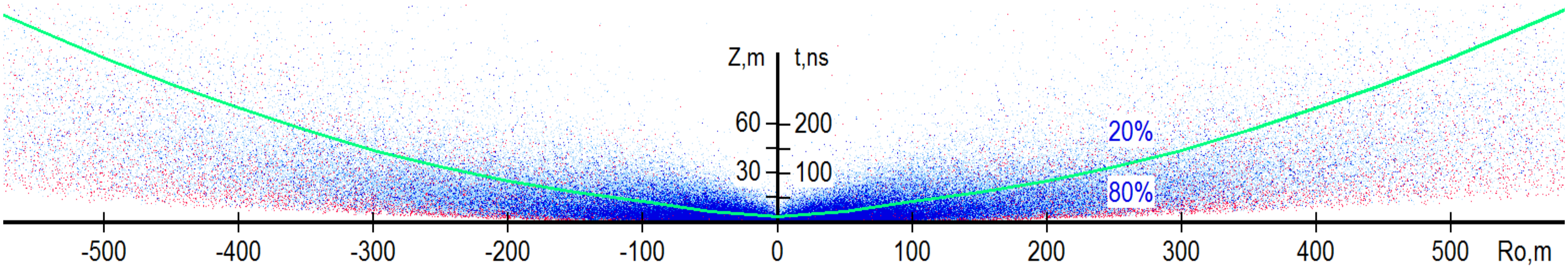
Primary: proton with $E=2\cdot10^{15}$ eV; 3340m above sea level

Red – muons, Blue – electrons

Below green line – 80% of particles. They carry most of EAS development information. Late 20% are born close to observation level

Above green line – 20% that were born in the later development stage

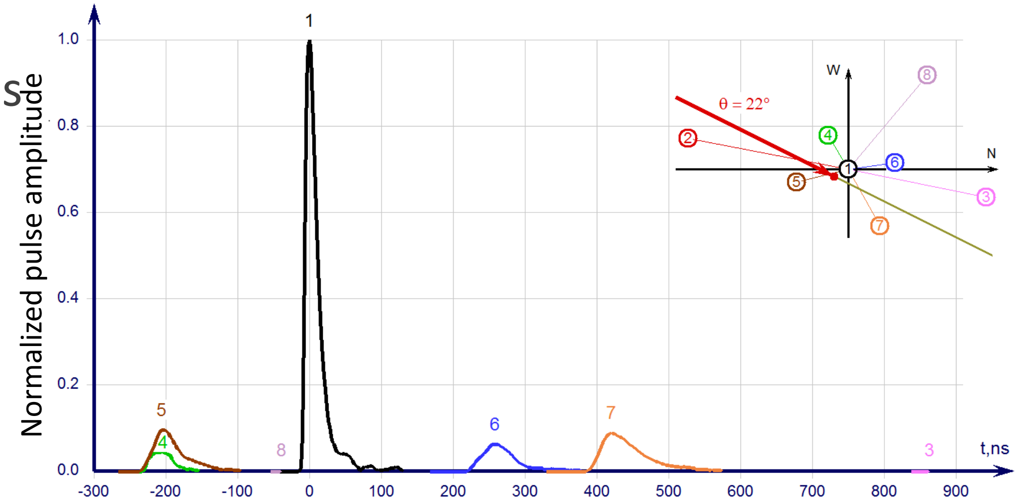
In analysis, we define pulse width as time interval that contains 80% of the pulse area.

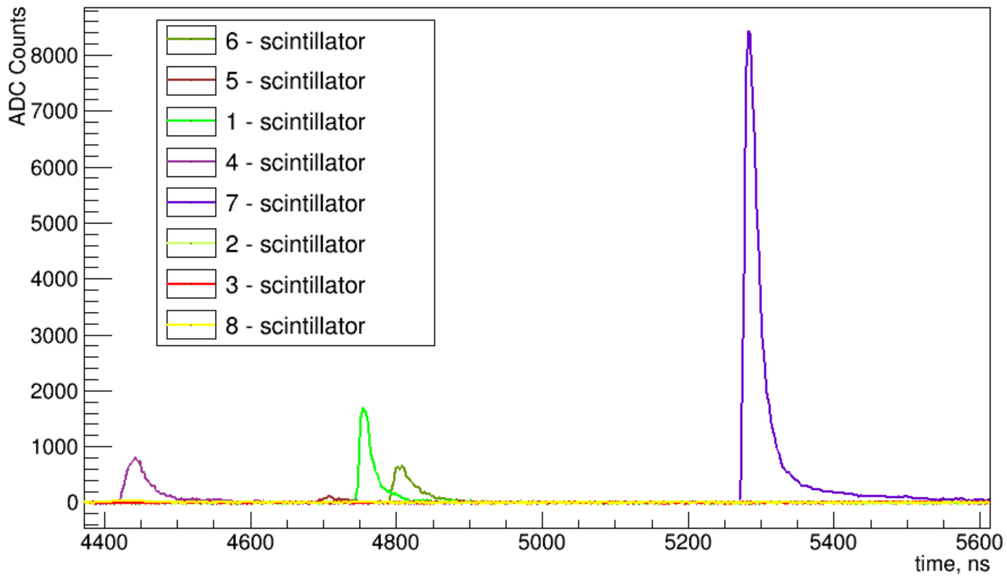


# Data for 'Standard' EAS

EAS signal from H10T detector that is in agreement with the simulation (modeled) data

Most of data at H10T




- Estimated Energy:
  - ~$10^{16}$ eV (top) at low angle
  - ~$2 \cdot 10^{16}$ eV (left) high zenith angle

# EAS model events summary

From simulation and current physics understanding, EAS should be a single disk with statistical variations in it.

Disk thickness increases from axis outwards

Particle density in the disk decreases from axis outwards

Large detectable variations should be extremely rare

- *EAS analysis methods developed on EAS with primary E about $10^{14}$-$10^{15}$ eV. Later thorough study extended that to $10^{16}$ (see slide 5), but no such study was above $10^{16}$ eV to prove validity is known.*

# Other types of events

An important part towards the understanding of the nature of cosmic rays is the study of the Extensive Air Showers (EAS) with delayed particles. Jelley and Whitehouse were the first ones studying these type of EAS in 1953 [1]. Later, EAS exhibiting the unusual time structures were studied by independent experiments such as [2-5] and others. All these studies concluded that EAS with delayed particles cannot be explained using known physical processes.


1. J V Jelley and W J Whitehouse. *1953 Proc. Phys. Soc. A* **66** (454), 1953
2. J. Linsley and L. Scarsi. *Phys. Rev.* **128** (2384), 1962
3. Baxter A.J., Watson A.A., Wilson J.G. *Proc. 9 ICRC.* **2** (724), 1965
4. H. Sakuyama, N. Suzuki, and K. Watanabe. *Nuovo Cim. A* **78** (147), 1983
5. Fomin Yu.A., Garipov G.K. et al., *Proc. 28 ICRC*. **1** (973), 2003

# Multi-modal [2] event example

Event from 22h31m05s April 6th, 2018; detection point #9

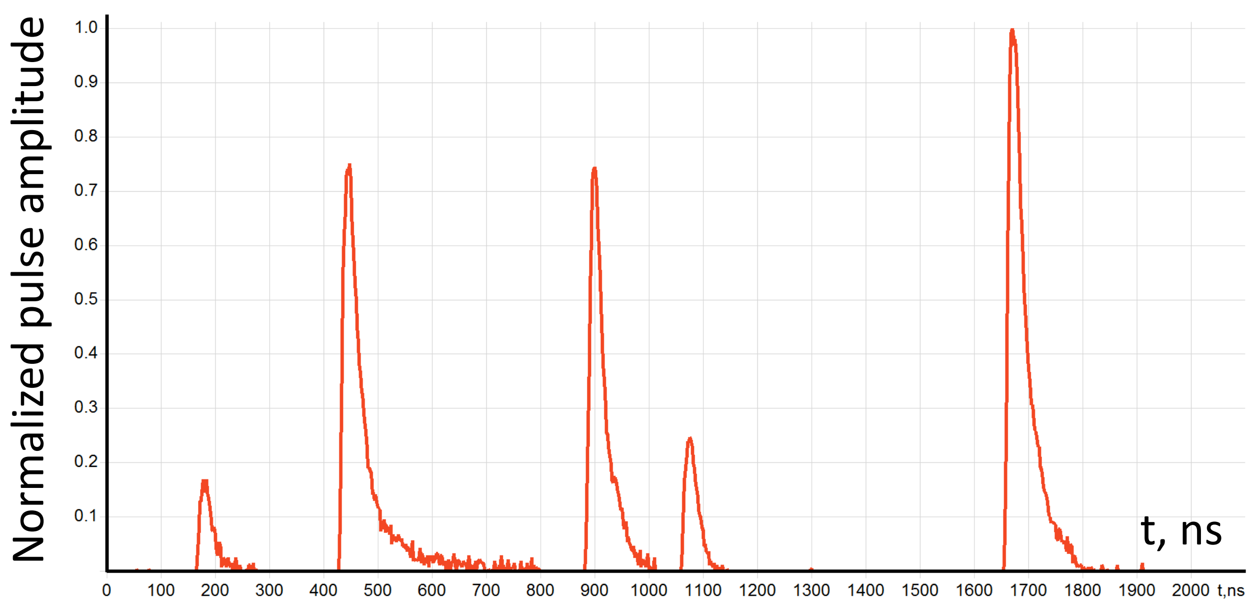
From South, zenith angle of ~52°

Pulses (or MODES) from 1 m$^2$ scint. detector ~989m from axis

From standard: expected 1 pulse, ~600ns wide, low particle density

Can not be explained by physics models in CORSIKA

*For each pulse, table lists the peak number, delay from the first peak, width from 5% to 80% of area and particle density at that detector.*




| Peak # | Delay ns | $\tau_{0.8}$ ns | $\rho_{0.8}$ #/m$^2$ |
|---|---|---|---|
| 1 | 0 | 28 | 32 |
| 2 | 265 | 34 | 256 |
| 3 | 720 | 31 | 187 |
| 4 | 894 | 31 | 52 |
| 5 | 1493 | 35 | 339 |

# Multimodal events analysis – open questions

Horizon-T data shows that all events below ~$10^{17}$ eV – 'standard'

Majority of events above ~5 $10^{17}$ eV exhibit some features of multimodal events

What analysis can be applied to such events?

Only for evens that have 2 pulses in all or some detection points – bimodal events:

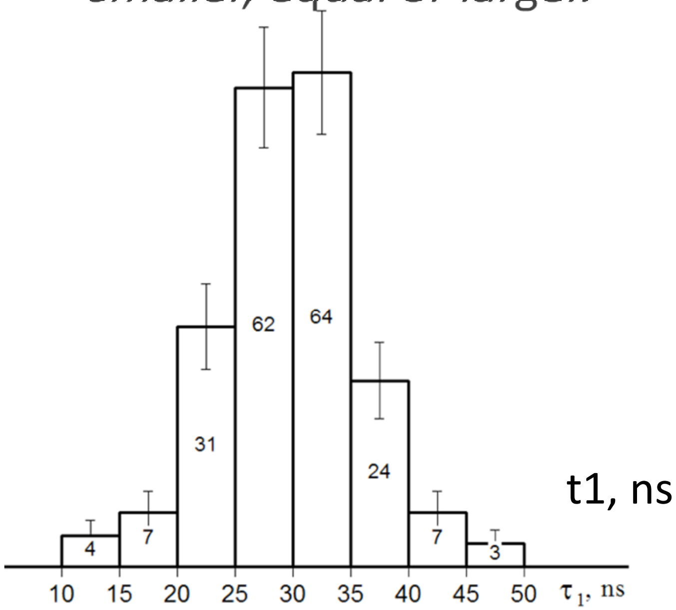
- Second peak width/amplitude vs. delay
- Correlation of width/delay
- Width of both peaks vs. distance from axis
- Particle density in each peak vs. distance from axis
- Others?..

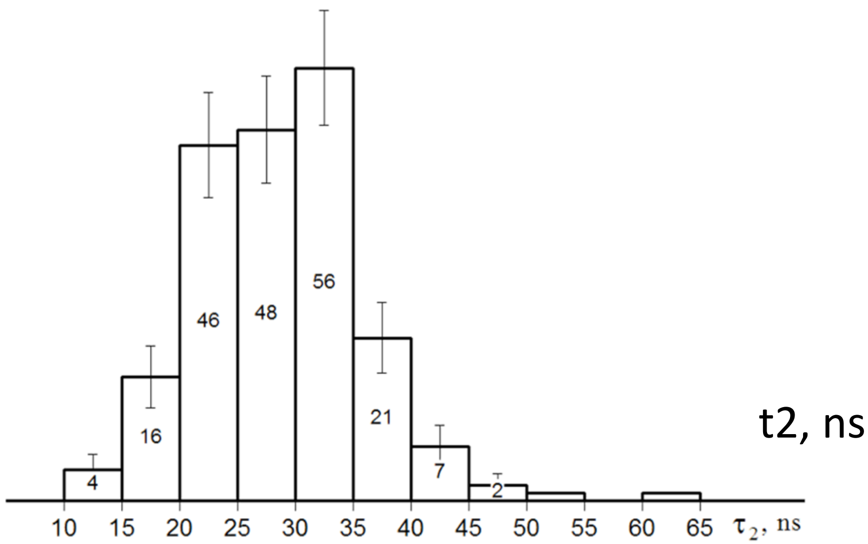
Can higher number of pulses be analyzed? New methodology needed?

# Bimodal events: Durations of each pulse

For 202 events that have 2 pulses in individual detectors (bimodal events), the pulse width shows no significant difference between 1st and 2nd pulses.

Pulse **amplitude/area** also shows no correlation with order – 2nd can be smaller, equal or larger.

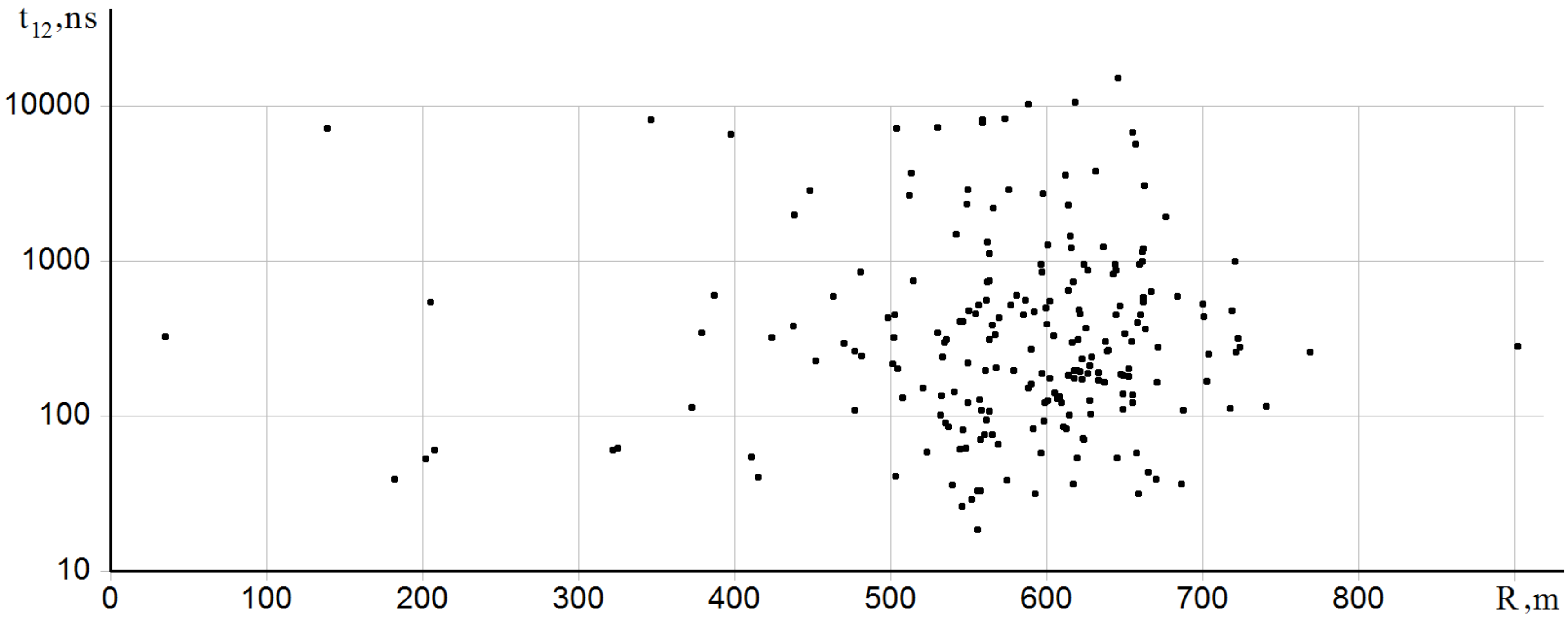


# Second pulse delay vs. distance from EAS axis

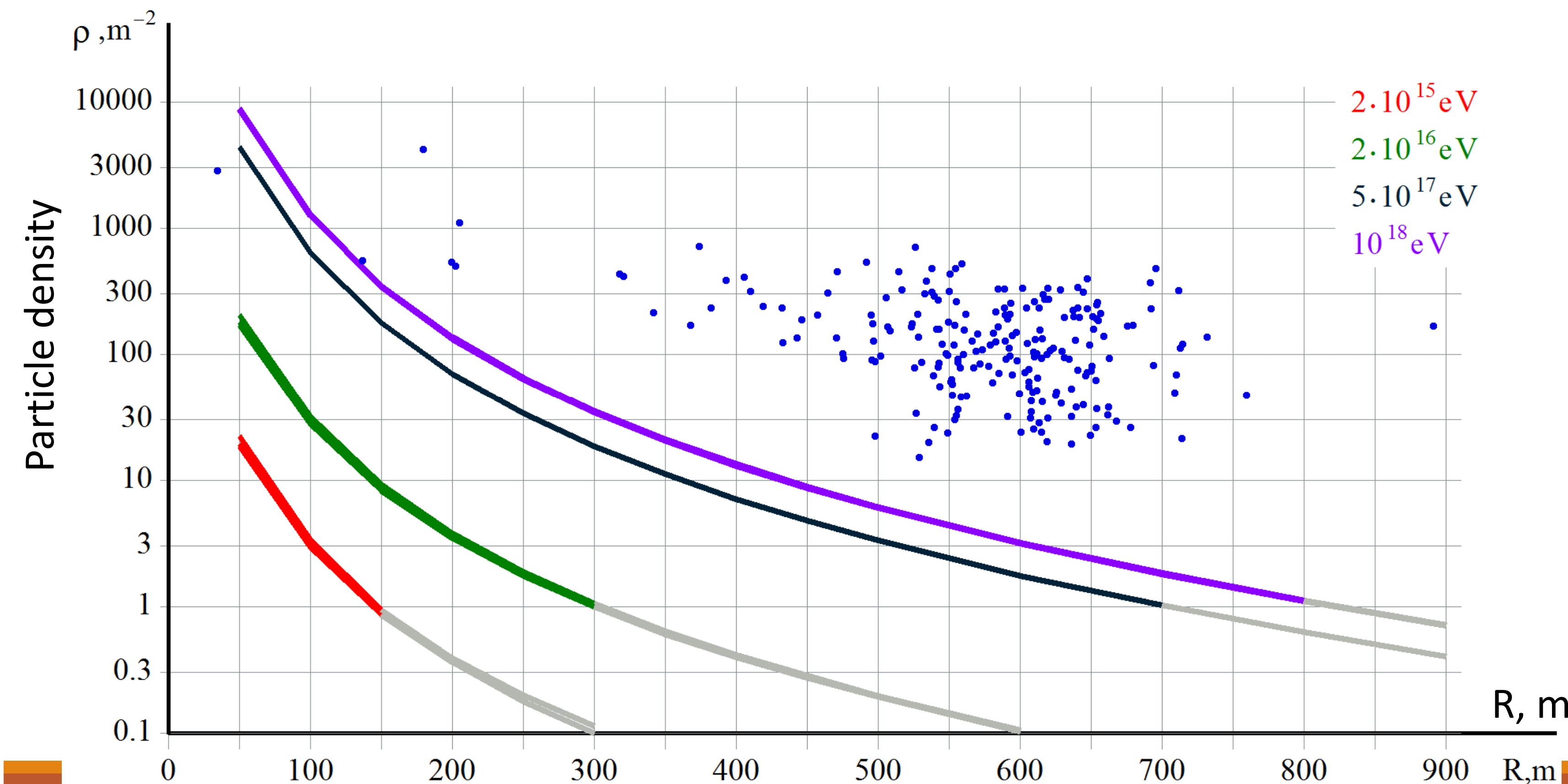
In bimodal events at detection point 9

No correlation is present



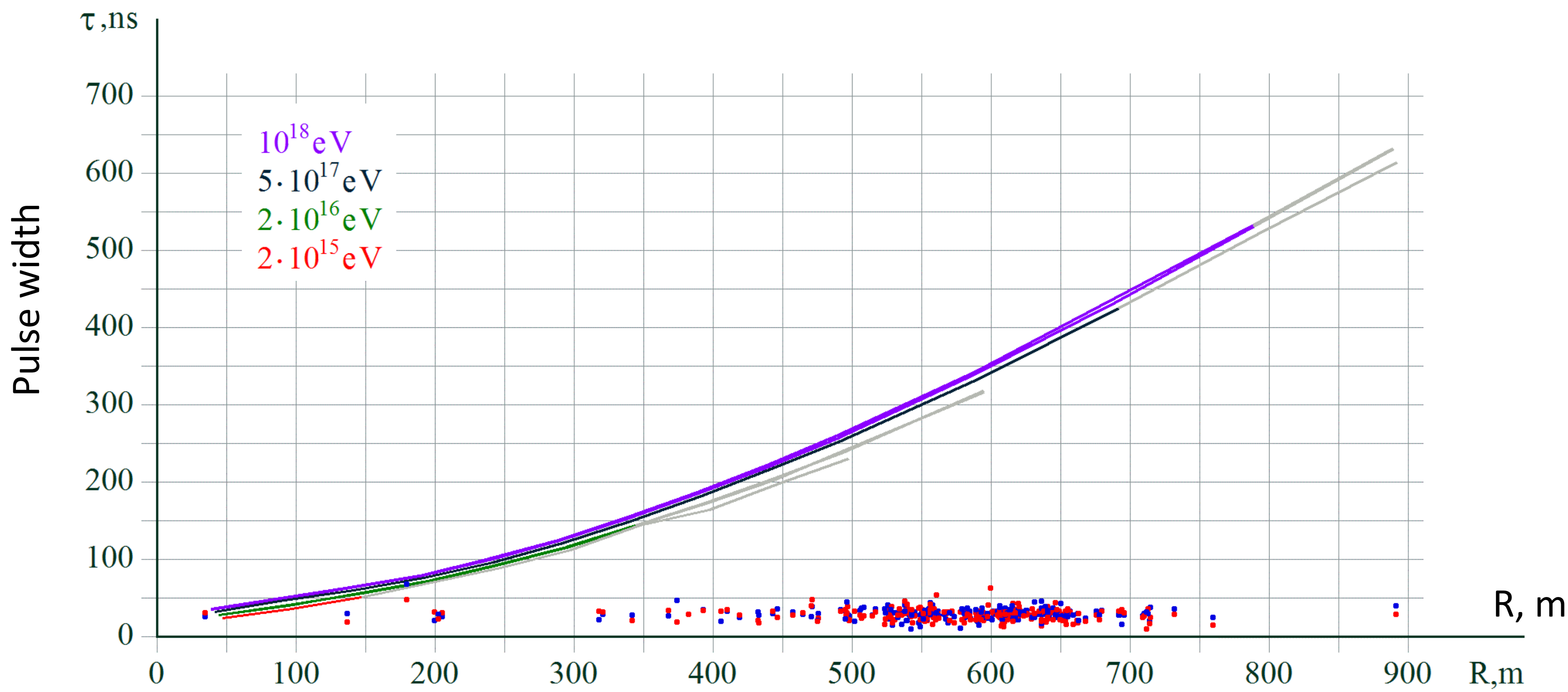
# EAS particle density (bimodal events)

For the same events at detection point 9



# EAS pulse widths (bimodal events)

For the bimodal pulses at detection point 9 only



# Conclusion

Horizon-10T is the EAS detection system with few ns time resolution

Above ~5 $10^{17}$ eV, multiple multimodal events detected

- With 2 or more peaks in several detection points

These events exhibit features that can not be reproduced using CORSIKA simulation package

Comprehensive systematic work affirms these effects to be observables

- Indicator of physics not in the simulation
- Analysis methodology needs to be extended

Future plans:

- HT-US (former HT-KZ) detection system to continue detailed study of unusual events

  Tileubek Uakhitov, Ayan Batyrkhanov, Dmitriy Beznosko, Alexander Iakovlev, Shotan Jakupov, Amir Kaipiyev, Arailym Konysbayeva, Alikhan Yeltokov, Kamilya Yessimbet and Valeriy Zhukov, "HT-KZ detector system: R&D considerations and prototype performance", EPJ Web of Conferences, Volume 208, 08009 (2019) https://doi.org/10.1051/epjconf/201920808009  ISVHECRI 2018

# References


[1] Rashid Beisembaev, Dmitriy Beznosko, Kanat Baigarin, Ayan Batyrkhanov, Elena Beisembaeva, Oleg Dalkarov, Alexander Iakovlev, Vladimi Ryabov, Turlan Sadykov, Sergei Shaulov, Marina Vildanova, Tileubek Uakhitov, Valeriy Zhukov, "Performance of Horizon-10T detector system in Physics Run 1", EPJ Web of Conferences, Volume 208, 08008 (2019) https://doi.org/10.1051/epjconf/201920808008 ISVHECRI 2018

[2] Rashid Beisembaev, Dmitriy Beznosko, Kanat Baigarin, Ayan Batyrkhanov, Elena Beisembaeva, Oleg Dalkarov, Alexander Iakovlev, Vladimi Ryabov, Turlan Sadykov, Sergei Shaulov, Marina Vildanova, Tileubek Uakhitov, Valeriy Zhukov, "Extensive Air Showers with Unusual Spatial and Temporal Structure", EPJ Web of Conferences, Volume 208, 06002 (2019) https://doi.org/10.1051/epjconf/201920806002 ISVHECRI 2018

[3] D. Beznosko, T. Beremkulov, A. Iakovlev, S. Jakupov, D. Turganov, A. Tussipzhan, T. Uakhitov, M.I. Vildanova, A. Yeltokov, V.V. Zhukov."Horizon-T Experiment Upgrade and Calibration of New Detection Points", arXiv:1803.08309 [physics.ins-det], Mar 22, 2018.

[4] R.U. Beisembaev, D. Beznosko, E.A. Beisembaeva, A. Duspayev, A. Iakovlev, T.X. Sadykov, T. Uakhitov, M.I. Vildanova, M. Yessenov and V.V. Zhukov, "Fast and simple glass-based charged particles detector with large linear detection range," Journal of Instrumentation, vol. 12, no. T07008, 2017.

[5]. HAMAMATSU PHOTONICS K.K., Electron Tube Division, 314-5, Shimokanzo, Iwata City, Shizuoka Pref., 438-0193, Japan, http://www.hamamatsu.com

[6].CAEN S.p.A. Via della Vetraia, 11, 55049 Viareggio Lucca, Italy. http://caen.it.

[7] R U Beisembaev, D Beznosko, K A Baigarin, A Batyrkhanov, E A Beisembaeva, T. Beremkulov, O D Dalkarov, A Iakovlev, V A Ryabov, N S Suleimenov, T Kh Sadykov, Z Tagay, T Uakhitov, M I Vildanova and V V Zhukov. "Horizon-T experiment and detection of Extensive air showers with unusual structure", accepted to Journal of Physics: Conference series, 2018

[8]. D. Heck, J. Knapp, J.N. Capdevielle, G. Schatz, T. Thouw. CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers, Forschungszentrum Karlsruhe Report FZKA (6019).

[9] D. Beznosko, A. Iakovlev, S. Jakupov, D. Turganov, A. Tussipzhan, T. Uakhitov, M.I. Vildanova, A. Yeltokov, V.V. Zhukov."Horizon-T Experiment Upgrade and Calibration of New Detection Points", arXiv:1803.08309 [physics.ins-det], Mar 22, 2018.