

Extensive Air Showers with Unusual Structure

Dmitriy Beznosko^{1,*}, Rashid Beisembaev², Kanat Baigarin¹, Elena Beisembaeva², Oleg Dalkarov², Vladimir Ryabov², Turlan Sadykov³, Sergei Shaulov², Aleksei Stepanov², Marina Vildanova², Nikolay Vildanov², and Valeriy Zhukov²

¹Nazarbayev University, Physics Department, Astana, KZ

²P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia

³LLP "Institute of Physics and Technology", Almaty, Kazakhstan

Abstract.

The total of 23500 Extensive Air Showers (EAS) with the energy above $\sim 10^{16}$ eV have been detected during the ~ 3500 hours of Horizon-T (HT) detectors system operations before Aug 2016. Among these EAS, more than a thousand had an unusual spatial and temporary structure that showed the pulses with several maxima (modals or modes) from several detection points of the HT at the same time. These modes are separated in time from each other starting from tens to thousands of ns. These EAS have been called multi-modal. Analysis shows that the multi-modal EAS that have been detected by Horizon-T have the following properties:

1. Multi-modal EAS have energy above $\sim 10^{17}$ eV.
2. Pulses with several modes are located at large distances from EAS axis.

The overview of the collected data will be provided. General comments about the unusualities of the structure of the multi-modal EAS will be presented.

1 Introduction

The Horizon-T [1] detector system is located at Tien Shan High-altitude Science Station (TSHSS) of Lebedev Physical Institute of the Russian Academy of Sciences at ~ 3340 meters above the sea level. It consists of eight charged particle detection points separated by the distance up to one kilometer as well as optical detector subsystem to measure the Vavilov-Cherenkov light from the EAS. The aerial view of the detector system is shown in Figure 1. The coordinates of each detection point with respect to the point 1 are given in a table 1.

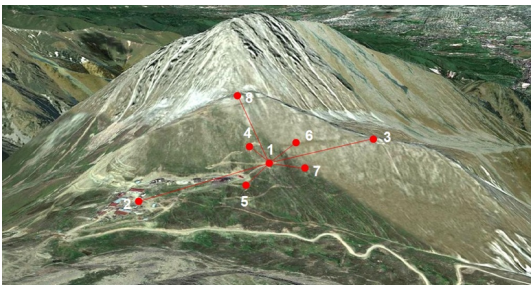


Figure 1. Aerial view of Horizon-T detector system.

HT is an innovative detector system constructed to study both the spatial and temporal distribution of the

charged particles within the EAS in the energy range above 10^{16} eV coming from a wide range of zenith angles ($0^\circ - 85^\circ$) with time resolution of few ns. This novel approach allows to collect two-fold the data from each detection point (particle density and time of passage) and increase measurement precision of the EAS parameters such as measuring the core position when it falls outside of the detector system area. The HT detector system consists of detectors of several different types: plastic scintillator [2] with MELTS [3] FEU49 model PMT, plastic scintillator with Hamamatsu [4] R7723 PMT assembly, glass with R7723 PMTs and a Vavilov-Cherenkov radiation detector with both FEU49 and Hamamatsu H6527 PMT assemblies. All detection points connect to Data Acquisition (DAQ) via cables that are being calibrated separately [5].

Table 1. HT detection points coordinates

Station #	X, m	Y, m	Z, m	R, m
1	0	0	0	0
2	-445.9	-85.6	2.8	454.1
3	384.9	79.5	36.1	394.7
4	-55.0	-94.0	31.1	113.3
5	-142.4	36.9	-12.6	147.6
6	151.2	-17.9	31.3	155.4
7	88.6	178.4	-39.0	203
8	221.3	262	160.7	374

*e-mail: dmitriy.beznosko@nu.edu.kz

From the start of a first prototype to August 2016, that is over ~ 3500 hours of HT detector system operations, 23500 EAS with the energy above $\sim 10^{16}$ eV, which is the threshold energy for HT. Among these EAS, more than a thousand had an unusual spatial and temporary structure that showed the pulses with several maxima (also called modes) from several detection points of the HT at the same time. These modes were separated from each other by time from tens to thousands of ns. These EAS are called the also called Multi-Modal Events (MME). Initially attributed to delayed particles, they were first observed by J. Jelly and W. Whitehouse [6].

2 Standard EAS definition

As a solid starting point, the definition of the 'standard' EAS is required. For that, we adopt the output of the EAS simulation package CORSIKA [7]. The simulated EAS serves as a reference that is simple to compare to, and allows to demonstrate certain simple properties of the EAS disk at the observation level.

Firstly, every parent particle regardless of species and energy gives rise to a single uniform EAS without any breaks in the structure or large-scale fluctuations with statistical significance.

Secondly, the particle density drops smoothly with distance when moving away from core. The symmetry is assumed here for the vertically incoming EAS disk. The charged particles distribution vs. the distance from core is illustrated in Figure 2. These simulation results are supported by the result of the experiment 'Hadron' published earlier [8].

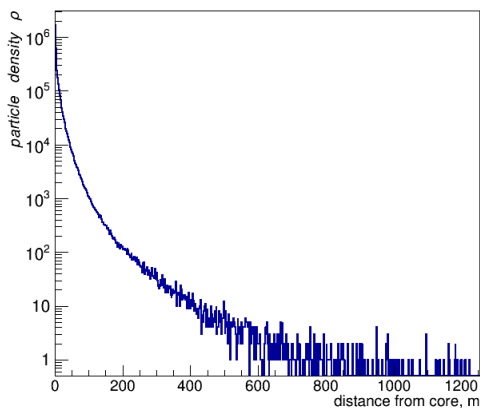


Figure 2. Charged particles density vs. distance from EAS core.

And, finally, the thickness of the EAS disk increases with the distance from the core. Additional characteristics may be sought from the simulated EAS but these three seem to be vital ones to both standard definition and the illustration of the unusualities of the EAS detected. For the illustration of the disk widening, the particles arrival time distribution over the 4 m^2 area at 50 and 100 meters is illustrated in Figure 3 and Figure 4 respectively.

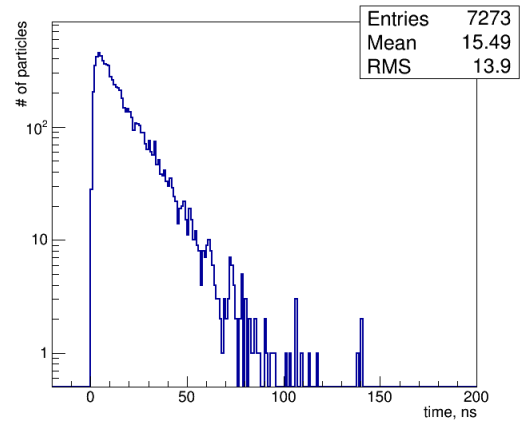


Figure 3. Charged particles arrival time at 50 m from EAS core.

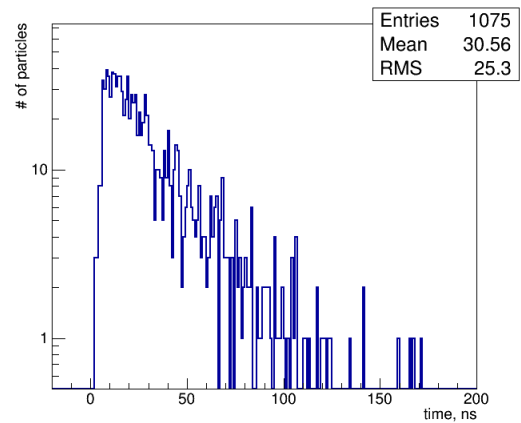


Figure 4. Charged particles arrival time at 100 m from EAS core.

In Figure 5 the event display of the standard EAS as detected by the HT detector system is shown. We can see that the EAS disk is arriving from the side of the detector point 4 grazing it with its edge, then hits points 5, 1 and 6 almost simultaneously with the core passing further then point 7 following the arrival direction.

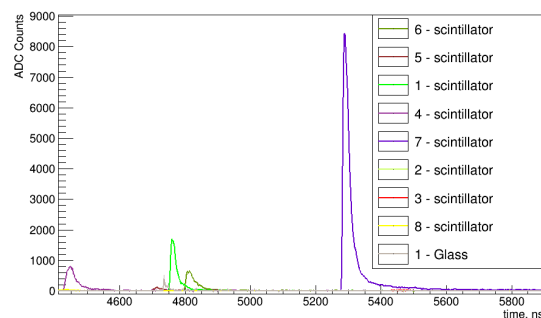


Figure 5. Sample 'standard' event as seen by HT detector system.

3 EAS with Unusual Structure

Besides the initial observation of the MME in 1953 [6], other scientists were trying to study these events at different times. Initially, the effect was attributed by many of them to a birth in the EAS of a very massive particle with a low γ factor that would get delayed and then start a new shower of its own, thus causing the multi-modality of the detected signals.

Over 60's to 80's, the MME events were studied by British and US physicists, such as Linsley J. [9], Watson A.A. [10] and Yodh G.B. [11]. Since the 70's, the delayed particle effect is studied in Japan (Sakuyama H. [12], Inoue N. [13]). Starting from the 80's, the studies of MME were continued by the Moscow State University [14] and in at Lebedev Physical Institute of the Russian Academy of Sciences [15] [16]. In the 90's, the MME pulses were registered at the Yakutst detector system [17], and in the 2000's they were detected by the "TUNKA" detector system [18].

Note that the delayed particle explanation, in order to support the time delayed observed experimentally, requires frequent birth of the particles with the rest masses exceeding 10^{12} eV. Not only we don't know such a particle, but, according to the current gauge invariance theories, the probability of such a particle being born is inversely proportional to the square of the mass contradicting the frequency of observation. Thus, the MME researchers have always admitted that they have extreme difficulties explaining the multi-modality using the current physics knowledge and that MME may indicate the existence of a new physical phenomena.

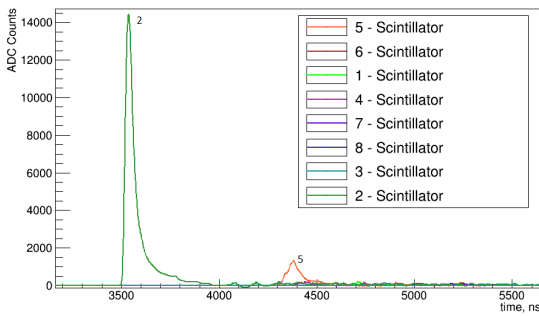


Figure 6. MME as seen by HT detector system.

3.1 MME Example at HT

Most MME events detected at HT seem to be parts of a larger event arriving far away from the detector system. However, there are several events recorded with the MME axis falling near one of the far periphery points, allowing to observe the complex structure of such an event. An example of such MME event is given below.

The event in Figure 6 was detected on Jan. 26 2016 at 3:51 UTC. The event display shows the very large signal at detection point 2 and and the next pulse is visible

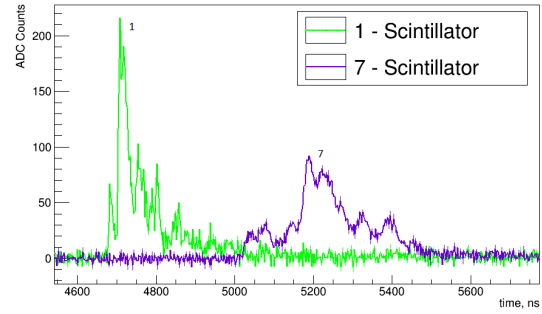


Figure 7. MME as seen by HT detector system.

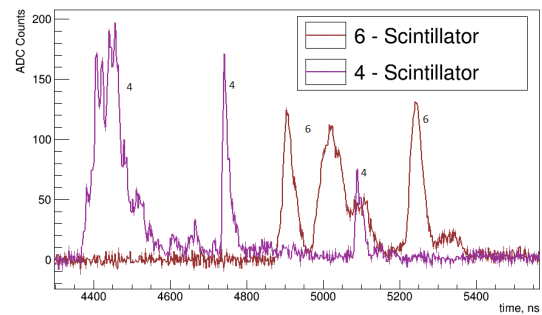


Figure 8. MME as seen by HT detector system.

from the point 5, thus indicating that the MME axis has arrived somewhere between these points much closed to point 2. The amplitudes of pulses from other detection points is much smaller and is not visible in this figure. If we take pulses with highest amplitude and use them as with a standard EAS analysis, then the axis of this event is tilted at $\theta \sim 50^\circ$ and arrival direction is approximately along the line, connecting detection points 2 and 3, deviating towards point 5. Note also that is a pulse from point 2 resembles what is expected from a standard EAS, the pulse from point 5 seems to start deviate from that expectation of a smooth pulse shape.

Shown in Figure 7 are the pulses from detection points 1 and 7 only. Note that these points are both located about the same distance from the axis and further then the point 5. Both have a complicated structure, with the signal from point 7 having the modes spread farther apart then for point 1 signal.

The pulses from detection points 6 and 4 display full multi-modality (see Figure 8). The peaks are separated by hundreds of ns and feature at least one of the pulses each having a complex shape.

The pulses from the detection points 3 and 8 are shown in Figure 9. These points are farthest from the axis of this event and display the features similar to points 4 and 6, except that the pulses have further separated by several hundreds of ns. Signal from the point 8 has the same 3 distinct modes, however, point 3 has only 2 modes visible. It is also the farthest point from the axis of the event, and it is possible that some modes are too weak to be detected.

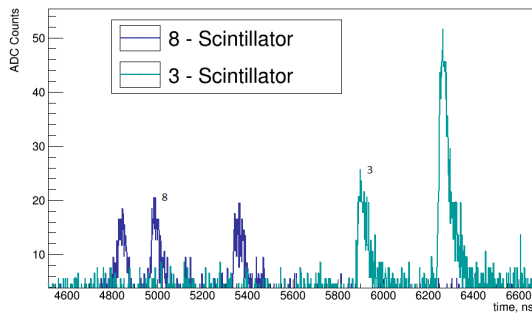


Figure 9. MME as seen by HT detector system.

From the pulses from all detection points we can infer that this is a very high energy event as its radius is at least 1 km. There are several clean events like this that have been observed at HT and they all follow the same pattern - a large single pulse (that may have structure that is just too fine to be resolved), then the complicated structure pulses at intermediate distances and fully separated multi-peaked pulses at the farthest points from the event axis. It is also plausible that other MME events detected are just parts of the events that have the structure described above. The further studies and analysis of such unusual events are in progress.

4 Conclusion

A large number of MME events were detected at HT. The observations show large variety of shapes and delays between the modes, thus discarding the hypothesis of the delayed particles, because in this case all detection points would have shown a similar structure. There is a strong indication that all the variety of forms detected comes from

the unified structure that was observed in several events with the axis close to the far periphery detection points, allowing observation of the event structure at different distances.

References

- [1] R U Beisembaev et al., arXiv:1605.05179, (2016)
- [2] A Baitenov et al., arXiv:1601.00086, (2016)
- [3] MELZ-FEU, 4922-y pr-d, 4c5, Zelenograd, g. Moskva, Russia, 124482 <http://www.meltz-feu.ru>
- [4] Hamamatsu Photonics, 314-5 Shimokanzo, Toyooka-village, Iwatagun, Shizuoka-ken, 438-0193 Japan <http://www.hamamatsu.com>
- [5] T Beremkulov et al., arXiv:1608.04312, (2016)
- [6] J.V. Jelly and W.J. Whitehouse, Proc. Phys. Soc. **A66**, 454 (1953)
- [7] D. Heck et al., Forschungszentrum Karlsruhe Report FZKA **6019**
- [8] Adamov D.S. et al., ICRC. **460A**, 5(1987)
- [9] Linsley J. and Scarsi L., Phys. Rev. **128**, 2384 (1962)
- [10] Baxter A.J., Watson A.A. and Wilson J.G., Proc. 9 ICRC. **2**, 724 (1965)
- [11] Yodh G.B. et al., Proc. 18 ICRC. **11**, 264 (1983)
- [12] Sakuyama H. et al., Proc. 16 ICRC. **8**, 135 (1979)
- [13] Inoue N. et al., Proc. 19 ICRC. **7**, 316 (1985)
- [14] Atrashevich V. B. et al., RAS News Bul. **58 (12)**, 98 (1994)
- [15] Beisembaev R.U. and Vavilov Yu.N. et al., Proc. 24 ICRC. Roma **1**, 454 (1995)
- [16] Beisembaev R.U. et al., Nuclear Physics T.72. **11**, 1-4 (2009)
- [17] Glushkov A. B. et al., Letters to Journal of Experimental and Theoretical Physics **67 (6)**, 361 (1998)
- [18] Prosin V. V. et al., RAS Bulletin **73 (5)**, 627 (2009)