The Upgrade of Horizon-T Detector

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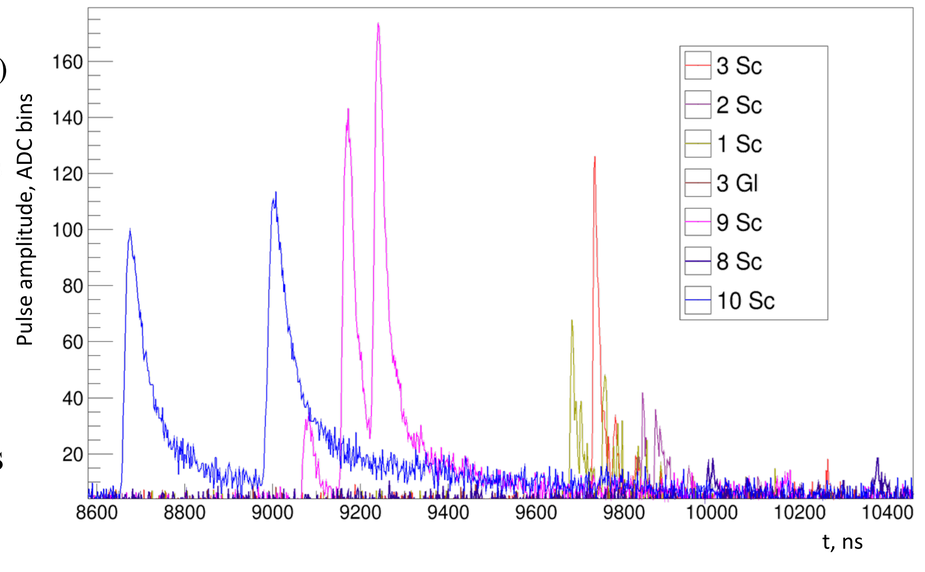
Background of Unusual Cosmic Ray Events

- An important part towards the understanding of the nature and interactions of cosmic rays with energy above 10^{16} eV is the study of the Extensive Air Showers (EAS) with delayed particles (also called unusual or multimodal events). 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 [2-6] and others. All these studies concluded that EAS with delayed particles cannot be explained using known physical processes.

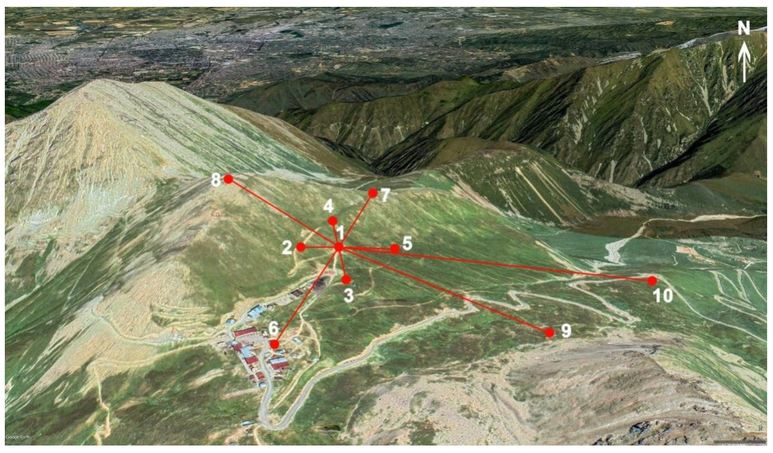
1. J V Jelley and W J Whitehouse. *1953 Proc. Phys. Soc. A* **66** (454), 1953
2. J. Linsley and L. Scarsi. *Phys. Rev.* **128** (2384), 1962
3. Baxter A.J., Watson A.A., Wilson J.G. *Proc. 9 ICRC.* **2** (724), 1965
4. H. Sakuyama, N. Suzuki, and K. Watanabe. *Nuovo Cim. A* **78** (147), 1983
5. Fomin Yu.A., Garipov G.K. et al., *Proc. 28 ICRC*. **1** (973), 2003
6. **Rashid Beisembaev et al., and others. 2019. "Spatial and Temporal Characteristics of EAS with Delayed Particles." In 36th International Cosmic Ray Conference (ICRC2019). Vol. 36.**

Example of Unusual Event: Zoom of event from 2h39m30s March 7, 2018



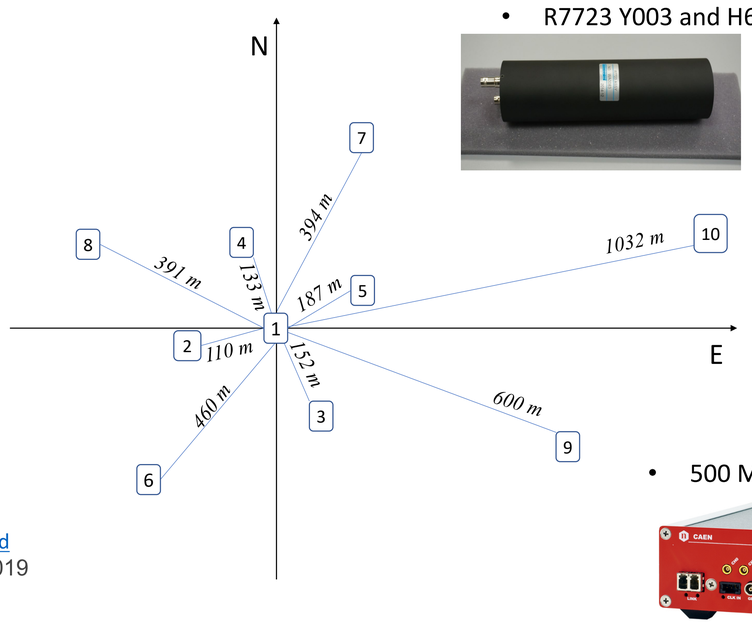
- Multiple pulses from 7 detection points shown
- They are correlated between detectors
- Only a single pulse from each detector is expected in a typical EAS event!
- Event axis is near point 7 (not shown)
- Clear peak separation is seen after ~400m away from the EAS axis.

Horizon-T Detector System Before Upgrade



- This configuration is in effect BEFORE Oct 26, 2019

Rashid Beisembaevet al.,.. "Spatial and Temporal Characteristics of EAS with Delayed Particles." In 36th International Cosmic Ray Conference (ICRC2019). Vol. 36. 2019



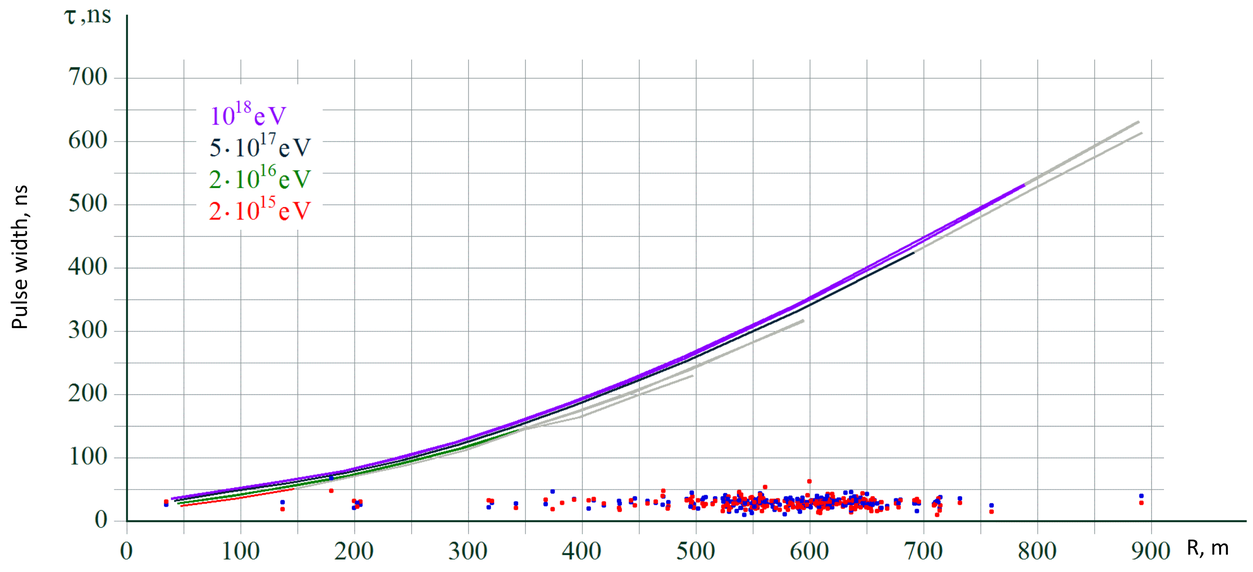
- R7723 Y003 and H6527 Hamamtsu PMTs

- 500 MHz CAEN DT5730 ADC

- Scintillator - based detector
  - ~7 ns pulse rise time

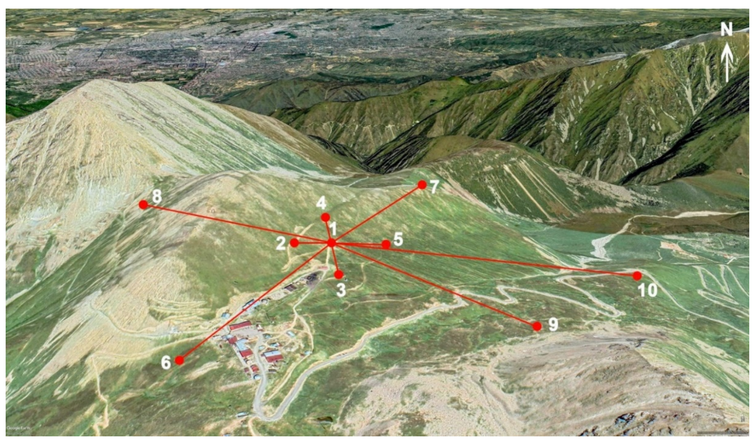
- Glass-based detector
  - ~2.1 ns pulse rise time

Previous Results Showed that ~600m from EAS Axis is most promising:

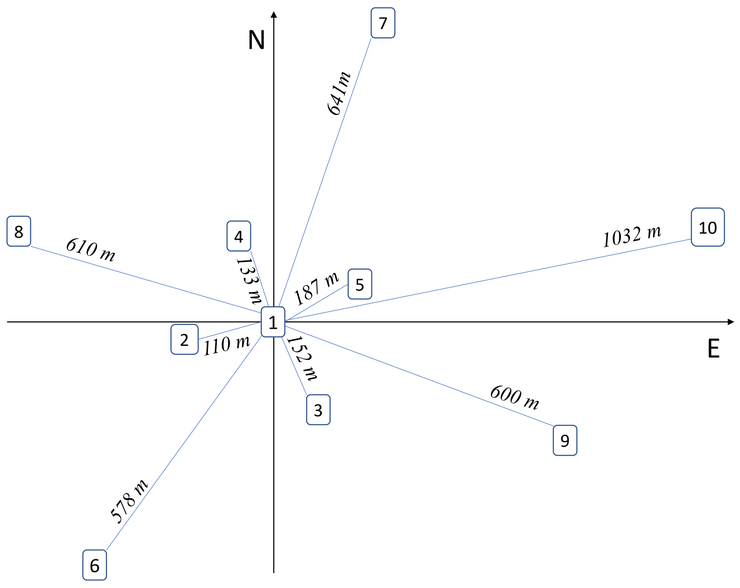


- The plot contains:
  - experimental data (blue dots – first pulse width, red – second pulse width) for bimodal events
  - the EAS disk width from the simulations for different E_0 (solid lines)
- Most bimodal events clearly separated thus best for analysis are found at distances > 400m from the EAS axis
- To enhance detection and increase the statistics of bimodal events it was decided to re-arrange the detectors to at 600m from center (point #1)

Horizon-T Detector System After Upgrade



Aerial view of Horizon-T detector system. This configuration is in effect from Oct 26, 2019, to March 4, 2020



- Detector points 6, 7 and 8 were moved to ~600m distance from detector center (point 1)
- In points 6-8, R7723 PMTs were replaced with H6527 on Dec 17, 2019.

Detector system acceptance and event rate estimate.

E_0 [eV]	10^{16}	$2\cdot10^{16}$	$5\cdot10^{16}$	10^{17}	$2\cdot10^{17}$	10^{18}
Γ [km² sr]	0.38	0.72	0.97	1.54	2.74	6.37
N/t [event/h]	25.60	7.98	2.25	1.05	0.53	0.07

Coordinates and distance R of each detection point from center (point 1), Detector and PMT type at each point.

№	Detector and PMT	X(m)(North)	Y(m)(West)	Z(m)	R(m)
1	Sc 1m², R7723	0.00	-0.00	0.00	0.00
1	Glass 0.62m², R7723	0.00	-0.00	0.00	0.00
2	Sc 1m², R7723	-51.84	92.80	27.60	109.82
3	Sc 1m², R7723	-146.58	-31.46	-21.50	151.45
4	Sc 1m², R7723	127.76	22.86	28.50	132.88
5	Sc 1m², R7723	88.88	-158.43	-42.40	186.54
6	Sc 1m², H6527	-504.53	281.10	-25.40	578.11
7	Sc 1m², H6527	578.33	-272.95	-42.50	640.92
8	Sc 1m², H6527	195.03	576.91	27.60	609.61
9	Sc 1m², H6527	-271.87	-525.76	-98.60	600.05
10	Sc 1m², H6527	228.36	-981.14	-225.30	1032.25

- **Conclusion**:
- From simulation and current physics understanding, EAS should be a single disk with statistical variations within it.
  - Disk thickness increases from axis outwards
  - Particle density in the disk decreases from axis outwards
  - Large detectable variations should be extremely rare
- HT detector system has detected numerous events that are of unusual structure
- HT detector has been optimized to maximize such events detection
  - **Future plans:**
- Using the upgraded Horizon-T detector, we plan to continue the detailed study of the unusual EAS events