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Extensive air showers event reconstruction using spatial and temporary particle distribution at Horizon-T experiment

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Abstract. A newly completed (Oct. 2016) detector system of Extensive Air Showers (EAS) called Horizon-T (HT) is a part of Tien Shan high-altitude Science Station of Lebedev Physical Institute of the Russian Academy of Sciences, which is located 32 km from Almaty at the altitude of 3340 meters above the sea level. Horizon-T is constructed to study Extensive Air Showers in the energy range above ~10^{16} eV coming from a wide range of zenith angles (0° - 85°). The system currently has eight working and two under construction charged particle detection points separated by the distance more than a kilometer. The ability to record each detector response with accuracy of 2 ns gives HT ability to study the temporary structure of EAS disk and apply the results to the event reconstruction. The reconstruction is therefore based on chronotron (< 0.5 ns), spatial and temporary distribution of charged particles within the detected EAS event. In this paper, we will show the simulated time distribution of charged particles in the EAS disk vs. distance from the axis and the correspondence to the data. A flow of the reconstruction of standard EAS events and the event display is presented as well as recent HT results.

1. Introduction

The Horizon-T (HT) detector system [1] [2] is a realization of ideas that were first formulated in [3]. The first results of the Horizon-T were published in [4]. The system currently has eight working and two under construction charged particle detection points [5] separated by the distance more than a kilometer. The ability to record each detector response with accuracy of 2 ns gives HT ability to study the temporary structure of EAS disk and apply the results to the event reconstruction.

When a primary cosmic ray (PCR) enters the atmosphere, it produces an Extensive Air Shower. EAS is a cascade of ultra-relativistic particles and Vavilov – Cerenkov radiation. For a vertically incoming EAS with primary particle energy of ~10^{17}eV, the disk formed by these particles at the distance 100m from its core pass the observation level in ~15-20 ns, and in just a few ns near the core. This was calculated using CORSIKA [6] EAS simulation software package version 7.5700.

A simulated particle density per m^2 distribution with the distance from the EAS axis for the vertical primary proton with 10^{17} eV at HT location is shown in Figure 1. The time that it takes for the EAS disk to pass the observation level also changes with the distance from axis. The particle distribution in time comes lower and wider as illustrated in Figure 2. The shown histograms of particle number per time bin are taken at different distances from the EAS axis in 20 m steps illustrating the sensitivity of the distribution to axis distance. If one would like to use this timing information, a detector used must have time resolution on the order of few ns. This timing information can be used in conjunction with particle density information for EAS analysis.

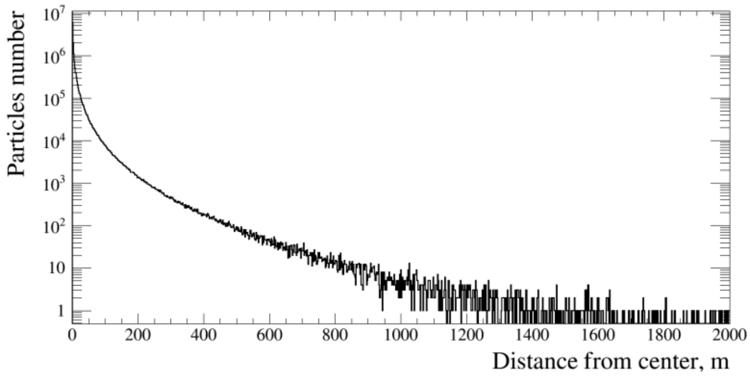

Figure 1: Particle density vs. distance from EAS axis for 10^{17} eV proton.

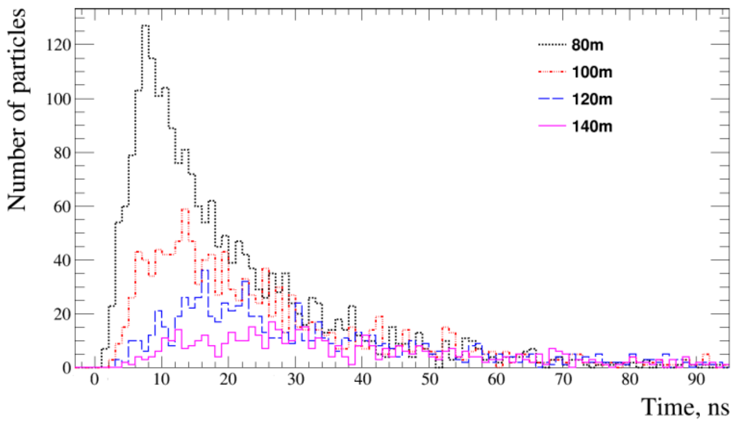

Figure 2: Number of particles arrival in time at different distances from EAS axis.

A typical, or standard, EAS event from HT is recorded as a single peak from each active detection point, with peak area increasing towards the EAS axis while width is decreasing. The event is triggered by a signal in points 5 and 6; the offline selection is done to require a clear signal from at least four detection points. The example of the "standard" event [4] is shown in Figure 3, with the event selected where axis is not passing near the detection point thus there is no single very large peak present. Pulses only from scintillator detectors are drawn. The pulse front time resolution for Sc are ~4-6 ns and for Gl are ~2-3 ns depending on the detection point distance to center.

The apparent thickness of the shower disks increases for the EAS arriving from larger zenith angles. The ability to conduct measurements near the horizon and the high time resolution give the name of the experiment: Horizon-T (where T stands for time). Developing on the HT ideas, there is also a project for a more advanced detector HT-KZ [7] [8] (HT-Kazakhstan) currently under construction.

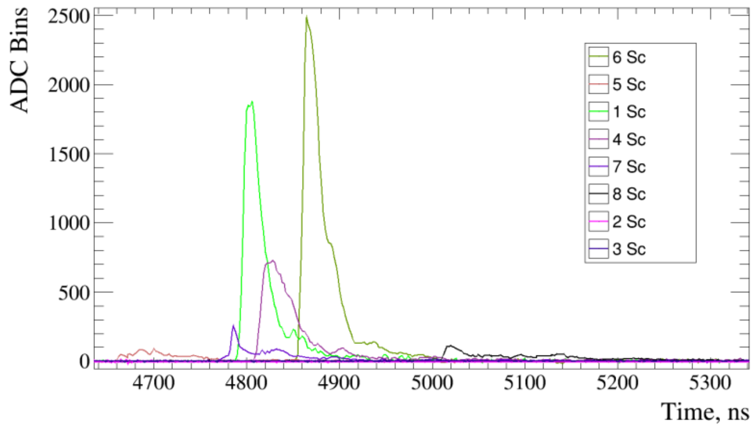

Figure 3: A typical EAS event at HT. Only scintillator detector responses are shown.

2. Reconstruction basics

The standard method of event reconstruction uses initial time of arrival of the event and the charged particles density distribution of the shower. On Horizon-T experiment, we use the whole pulse shape from every detector and CORSIKA simulation to reconstruct individual events.

HT detection points record the full waveform of the SD and GD (scintillator and glass detectors) response, thus providing the time distribution of the particles arrival time. To use this data for the analysis, the approximation procedure for the expected pulse at each detection point is defined. The pulse approximation uses the particle arrival time distribution provided by CORSIKA convoluted with the MIP calibration data for each detection point. All analysis is done on event per event basis only. Note that data analysis methodology is still in progress and current best results are provided. Final results will be reported in a separate work when completed.

3. Arrival direction and core position

The precision of the pulse arrival time measurement between HT farthest points (number 2 and 3) is ~1 ns and is better for others, down to ~0.4 ns. Thus, the hardware accuracy is very high (~0.1%). Initial guess for arrival direction is obtained using the EAS model as a plane and the time delays in EAS arrival to neighboring detection points (e.g. chronotron method).

For the second stage analysis, a fit of the data is done to the model using the approximated pulse for each detection point. The initial guess is used to take the proper CORSIKA simulated file and then adjust the arrival angle, core position and energy of the PCR to obtain the best fit possible. The resultant resolution of the arrival direction is model dependent, and in all cases, it is estimated to be better than ~0.5°.

At the same time, the position of the core and energy of the primary particle are found. The fitting process includes both the particle density decrease with distance from the core and the pulse shape widening. The core position accuracy depends whether it is inside the HT enclosed area or immediately outside and whether is it too close to the detection point resulting in detectors saturation. For the favorable conditions, core position uncertainty is estimated to be better than ~ 10 m. The use of described technique allows working with events whose core position falls in the vicinity of the HT area as well.

4. Energy of the primary particle

The energy of the primary is first estimated using the apparent size of the event (which detection points have signal and the strengths of these signals). Then this estimate together with the initial arrival angle and core position estimates are used to select the CORSIKA simulation file and produce the approximation pulses. The result is then fitted to the data. The approximation is rotated and scaled to get a better fit. Then resulting corrections to energy of the primary and arriving angles are used to select another simulation file and produce approximation pulses. Several iterations are done to achieve the best fit possible. Final result is compared to the one obtained using the lateral distribution function. This work is currently in progress, the best current result for the primary particle energy resolution is about 20%-25%.

5. Conclusion

A new method of reconstructing events uses full pulse shapes to find the core position, core axis direction and the energy of PCR. The fit of approximation pulses generated by CORSIKA simulation package to the real pulses converges after a few iterations and allows reconstruction of individual events. The Horizon-T detector system measures with high resolution (2ns) the internal structure of individual events and that is why by using small number of detection points (8 detectors) one can still reconstruct “standard” events with a good precision. The HT-KZ detector system will use the same reconstruction method when it will be constructed.

Acknowledgements

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