Fast Charged Particle Detector with High Dynamic Range  

at Horizon-10T Cosmic Rays Detector System

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Horizon-10T (H10T) detector system is constructed to study the Extensive Air Showers (EAS) with energy of the primary particle above $10^{16}$ eV. Detector system consists of 10 detection points. The aim of the H10T is the detailed study of the spatial and temporal structure of EAS events. For that purpose, each detection point should have high time resolution and high dynamic range, so that fast time response of the components is needed. H10T detection points are equipped with the PMT-based particle detectors with large detection area and ~2 ns pulse rise time that are currently among the fastest. Such detector consists of the 2 cm thick glass as the detection medium and Hamamatsu R7723 photomultiplier tube in a pyramidal shape. The detectors are calibrated to single minimum ionizing particle (MIP) signal and have a linear dynamic range up to 3000 MIP. Simulation, construction and calibration of this glass detector is presented.

**KEYWORDS:** cosmic rays, detector system, particle detector, glass detector

1. Introduction

Horizon-10T (H10T) [1] or H10T is the cosmic rays detector system constructed at Tien Shan High-altitude Science Station (TSHSS), Almaty, Kazakhstan. It is an upgraded version of Horizon-T (HT) detector system [2, 3, 4] aimed to study Extensive Air Showers (EAS) coming at wide range of zenith angles ($0^\circ$ to $85^\circ$) with energy of the primary particle of the detected events above $10^{16}$ eV. System is located at ~3340 meters above the sea level and consists of 10 charged particle detection points. Points are separated up to 1.3 km. Aerial view of the detector system is presented in the Figure 1.

Each H10T detector is equipped with a 1 m² polystyrene-based scintillator detector. Points 1-5 have an additional detector based on optically thick glass of 2 cm thickness. All detectors are equipped with Hamamatsu [5] R7723 photomultiplier tube (PMT). These PMTs have 1.7 ns pulse rise time, 1.1 ns time spread and work at maximum 2 kV bias. Data is recorded using 500 MHz CAEN [6] DT5730 digitizer.
2. EAS Temporal Structure and Detector Resolution Requirement

As EAS develops in the atmosphere, it shapes into a disk. However, that disk has a temporal profile (passage time, or width) as well. The schematic of this disk temporal profile at the detection level is represented in Figure 2. It is easy to note that the disk is very thin near the EAS axis and becomes extended with distance.

We accept as standard type [7] EAS event such as defined by simulation package CORSIKA [8] for the purpose of this study in order to obtain EAS disk parameters dependency. From the simulation details, we show that additional information about EAS can be obtained by analyzing its temporal structure. For this analysis, high time resolution is required.

CORSIKA simulation provides arrival time for each particle in the disk. The EAS arrival time at a detector is defined as the 50% of the particles at that detector. The arrival time for a vertical EAS is proportional to square of the distance. This arrival time

![Fig. 1. Aerial view of Horizon-10T detector system with all detection points labelled.](image1)

![Fig. 2. Schematic of EAS disk temporal profile at detection level from simulation. Blue line is the 10% of the overall particle density at ground detector, red – 90%, representing the disk width.](image2)

![Fig. 3. Disk arrival time (left) and disk width (right) vs. distance from the EAS axis from simulation.](image3)
data is normally used to get the EAS arrival direction by using data from 3 or more detectors. Time resolution is required for this on the ~ns level.

The disk width is defined as the time difference between 10% and 90% of the arriving particles at each detector; it depends linearly on the distance from the EAS axis and can assist in determining the EAS axis location. Simulated results for disk arrival time and disk width as a function of distance from the EAS axis are shown in Figure 3.

The time resolution required to accurately measure EAS temporal characteristics is on the order of few ns. Large detection area and detection range are also required.

Fig. 4. Illustration sample from glass detector simulation (left) and detector prototype (right). In green is the 2 cm thick glass, blue - structural support, red – photons paths, black circle – PMT.

3. Glass-based Detector with High Time Resolution

Figure 4 (left) is the illustration frame from the full simulation of the glass-based detector. The green rectangle is the 2 cm thick glass (chosen due to availability), red lines are paths of individual photons from a passing particle, and black circle is the PMT. Blue lines are the support structures and outer casing as seen in Figure 4 (right).

The simulation purpose was to optimize the PMT placement such as distance from the glass and position at the same side as arriving particles (top) or on the opposite side (bottom). Each ultra-relativistic charged particle produces the Cherenkov light in glass that is directed along its path, from top to bottom. The light detector thus is placed at the bottom to intercept incoming light. However, both the simulation and prototyping showed that the placement of the PMT at the top and painting the bottom face of glass with TiO₂ drastically increases detection uniformity. The uniformity is defined as the
similarity in detector response to Minimally Ionizing Particle (MIP) arriving across the glass top face. Here it's presented as the average ratio of the MIP pulse areas from the detector corners to the MIP pulse areas from the center (directly under the PMT face).

Figure 5 (left) is the simulation result for the detection uniformity dependence on PMT distance from glass face. This distance is limited by a plot in Figure 5 (right) showing that number of detected photons per MIP reduces with distance.

Single photoelectron (PE) spectrum using LED was taken for the R7723 PMT at different bias voltage (Figure 6 left). Then the detector has been calibrated using MIP signal – so we know the average number of photons detected by a PMT per one MIP detection. Next step was the calibration of the PMT response to the PIN diode reference at the same time from the same light source (details are provided in [2]). The results are shown in figure 6 (right). Numbered points are: 1 – deviation from linearity is less the 2%; 2 – deviation is less than 10%, 3 – ADC saturation for PMT signal is reached.

When operated at ~1500V bias, the linearity of the response within 10% of glass detector is up to 300 MIP signals.

With the chosen parameters, the glass detectors used for upgrade have the ~2 ns signal rise time and linear detection of up to 3000 MIP [2]. These characteristics are among the fastest PMT-based detectors and are applicable from H10T purposes.

4. Conclusion

A fast glass-based charged particles detector with large detection area has been simulated, tested and constructed. The best time resolution possible for the PMT + glass with 0.25 m² detection area for 2 cm thick glass is the ~2 ns pulse rise time. The linearity of response for this detector is up to 3000 MIP that is beneficial for EAS detection.
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