

Status of the HiSCORE experiment

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Abstract: The new HiSCORE detector concept is based on Cerenkov air-shower detection, using the non-imaging technique. HiSCORE is build for gamma-ray astronomy from 10 TeV to several PeV, and cosmic rays studies from 100 TeV to 1 EeV. It will search for "Pevatrons" (ultra-high energy gamma-ray sources), and measure cosmic ray composition and spectrum in the transition range from a supposed Galactic to extragalactic origin of cosmic rays.

The detector is made of wide-angle optical stations (0.6 sr) placed at distances of 150-200m, and will cover an area of 1 km² - 100 km², to be deployed in various stages.

We report on status and plans of the Tunka-HiSCORE installation, in the Tunka valley near Lake Baikal, from first prototypes operating now to the > 1 km² arrays envisaged for the near future.

Keywords: Gamma Astronomy, Cosmic Rays, New Technologies, HiSCORE.

1 Introduction

We plan to explore the so far poorly measured gamma-ray sky in the energy region from 20 TeV to several PeV with the large area wide-angle detector Tunka-HiSCORE. The sensitivity level of presently existing and planned gamma telescopes is optimized for the energy range 100 GeV-20 TeV, γ -rays with energies above 10 TeV were detected from only 10 sources by now. No γ -ray sources with energies higher than above 100 TeV have been detected. For the energy range above 20 TeV (ultra high energy gamma-astronomy), there is a number of fundamental issues which so far have no answers. Most importantly, clear evidence is needed for sources of Galactic cosmic rays around 1 PeV, in the immediate vicinity of the classical knee in the all particle cosmic ray spectrum, discovered more than half a century ago - which so far does not have a convincing explanation. The Tunka-HiSCORE detector will also measure the composition and energy spectrum of charged Galactic cosmic rays up to 100 PeV, will study diffuse γ -ray emission, γ -ray absorption on the background radiation (infrared and microwave), and will search for photon-axion transitions.

This paper gives an overview on the Tunka-HiSCORE project - it's main purpose and design features (section 2) and the current status and plans (section 3).

2 The Tunka-HiSCORE project

The Tunka-HiSCORE array will consist of optical stations, distributed over a large area, and will be located at the site of Tunka-133, an EAS Cerenkov light experiment [5, 6] in the Tunka valley in Siberia, about 50 km from Lake Baikal.

Tunka-HiSCORE is a non-imaging Cherenkov light-front sampling array, made of many large area and wide-angle optical detector stations, that make up an array with a total area of ~ 1 km² in the initial phase, and up to 100 km² in a final phase. The principle of the Tunka-HiSCORE detector follows the idea outlined in [1]. The detector stations measure the light amplitudes and full time development of the air shower light front up to distances of several hundred meters from the shower core.

According to MC-simulations, the 5-year integral flux-sensitivity for point sources will be about $2 \cdot 10^{-13}$ erg/cm²sec⁻¹ (10^{-12} erg/cm²sec⁻¹) at 300 TeV for a 10 km² (~ 1 km²) array, respectively. The sensitivity as function of energy for 10 and 100 km² instrumented area is given in fig.1, and compared to other detectors under construction (see ref. [4] for details). The sensitivities give an estimation of the Tunka-HiSCORE capabilities, they are conservative both for the low and high energy region, since they are based on a standard, regular 150 m grid station spacing (neither optimal for the low nor the high energy part) and on first level analysis algorithms.

Table 1 gives a selection of multi-TeV γ -sources that are

Object	RA [deg]	Dec [deg]	F (1TeV) [$10^{-12} \text{cm}^{-2} \times$ $\text{s}^{-1} \text{TeV}^{-1}$]	F (35TeV) [$10^{-17} \text{cm}^{-2} \times$ $\text{s}^{-1} \text{TeV}^{-1}$]	T_{obs} [h]		$N_{ev}(>20\text{TeV})$	
					Tilt=0°	Tilt=25°	Tilt=0°	Tilt=25°
Tycho SNR (J0025+641)	6.36	64.13	0.17 ± 0.05 $\Gamma=1.95 \pm 0.5$		145	233 north	54 ($\Gamma=1.95$)	88 ($\Gamma=1.95$) north
Crab PWN PSR	83.6	22.01	32.6 ± 9.0 $\Gamma=2.6 \pm 0.3$	162.6 ± 9.4	8	110 south	44	605 south
SNR IC443	94.18	22.53	0.58 ± 0.12 $\Gamma=3.1 \pm 0.30$	28.8 ± 9.5	22	112 south	0	2 south
Mkn421 BL (z=0.31)	166.11	38.20	50-200 $\Gamma=2.0-2.6$		140	116 south	22-90 ($E_{cut}=5\text{TeV}$) 80-3200 ($E_{cut}=16\text{TeV}$)	18-75 ($E_{cut}=5\text{TeV}$) 660-2600 ($E_{cut}=16\text{TeV}$)
CasA SNR	350.85	58.81	1.26 ± 0.18 $\Gamma=2.61 \pm 0.24$ ± 0.2		133	177 north	32	40 north

Table 1: Selected northern sky γ -ray source candidates (see [7]) for Tunka-HiSCORE. Known fluxes $F(E)$ at 1 TeV and 35 TeV and spectral indices Γ are given; observation Times T_{obs} for the Tunka-site are shown for vertical station alignment (Tilt=0°) and for tilting 25° towards north or south (Tilt=25°). Expected number of events N_{ev} for an 1 km² array for $E>20$ TeV are given for both tilt-modes. Fluxes in column 4 (5) are from IACTs (Milagro).

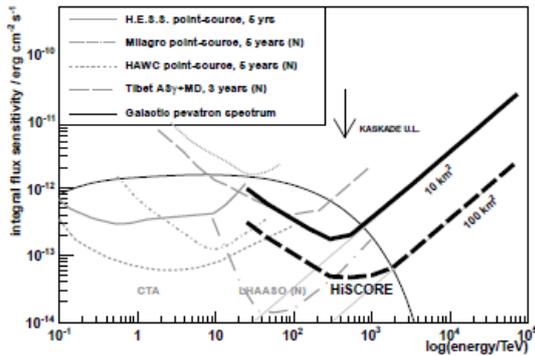


Figure 1: HiSCORE 5-year point-source survey sensitivity for 10 and 100 km² instrumented areas. For details, see [4]. HiSCORE sensitivities are conservative (no optimized array layout and default analysis procedure).

within the field of view at the Tunka-site (see TeV-catalogue [7]). Observation times T_{obs} (for October-April, multiplied by 0.5 for weather conditions) are given in column 6 for nominal station layout, ie. when all stations are vertically aligned (Tilt=0°). Corresponding event numbers N_{ev} for an 1 km² array and energy threshold 20 TeV are given in column 8. By tilting all stations either northwards or southwards, increased source coverage can be obtained, as given in column 7 and 9. We note, that tilting 25° south increases N_{ev} from 44 to 605, as well as tilting north almost doubles the Tycho event rate.

2.1 Optical station and array layout

Each optical station will, in the baseline design, consist of four large area photomultipliers (PMTs) with 20 cm diameter, as shown in fig.2. Each PMT will have a Winston cone with 0.4 m diameter and 30° viewing angle, with a

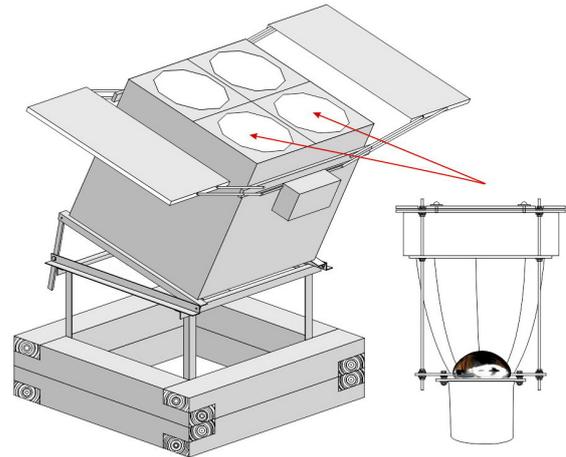


Figure 2: The optical station of the Tunka-HiSCORE array: 4 PMTs with winston cones, with a mechanism to incline the station into northern or southern direction.

total station light collection area of 0.5 m², and a field of view of about 0.6 sr. To optimize the observed sky-region, a tilting mechanism allows the stations to be tilt into the northern or southern direction by up to 25°, as indicated in fig.2. The resulting sensitivity improvement for selected sources is large, as given in table 1. Using PMTs with improved parameters (10-inch diameter, up to 35% photocathode sensitivity) as well as wavelength-shifter coating of the PMTs is considered, aiming at lowering the energy detection threshold [8].

An optical station will be equipped with a data acquisition system (DAQ) to record PMT pulses with GHz sampling (anodes and dynodes, for improved dynamic range). Stations act independently for triggering and readout; the station trigger is based on summing PMT anode signals after clipping [1]. Relative time synchronization for the recorded light pulses between all stations of (sub)-nsec precision is needed, to reach best angular resolution (about 0.1° for gammas above 200 TeV) [2]. Two technologies are

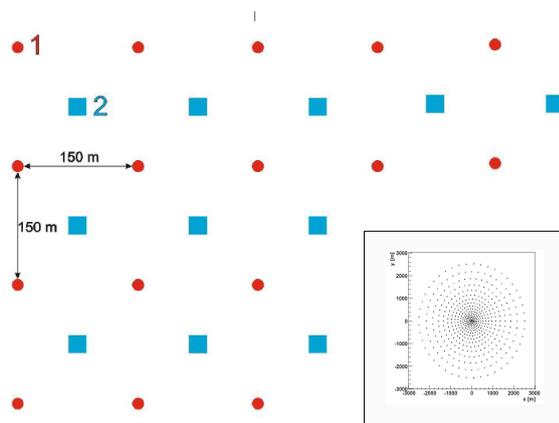


Figure 3: Sketch of possible array layouts for HiSCORE stations. *Left:* regular grid of optical stations with 150 m spacing (red dots) for a $\sim 1 \text{ km}^2$ array. Optional infill with additional stations to lower the energy threshold (eg. 10-inch PMT-based; blue symbols). *Right:* a large-scale spiral array layout (20 km^2), with a low-energy central part (denser) and an outer high-energy part (sparser instrumentation).

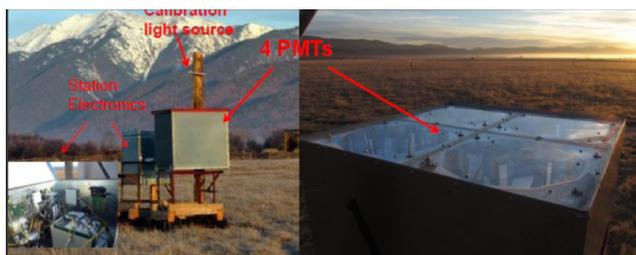


Figure 4: View of the optical and electronics container of a HiSCORE prototype station, deployed fall 2012. The insert (left) shows both the new and old DAQ components. On the right, the four Winston cones and PMTs, below the plexiglass cover of $\sim 0.5 \text{ m}^2$, are displayed.

currently under consideration. Slow control functionality will be available for PMT-high voltage, DAQ and environmental control. The station will be made of a metal container, with a remote controlled lid opening/closing mechanism.

The geometric arrangement of the optical detectors in the Tunka-HiSCORE array is currently being optimized, especially to optimize for a relatively low energy threshold (a few 10 TeV). Figure 3 (left part) presents the baseline array design: a regular grid layout with 8" PMTs at 150 m distance, which will be for the inner $\sim 1 \text{ km}^2$ part of the array. To lower the detection threshold, an infill with additional stations for part of the area is under discussion (likely with higher sensitivity PMTs). For optimal performance at highest energies, larger station distances can be tolerated outside the core array region. Figure 3 (right) shows an 5 km diameter array design with a spiral structure, with enlarging station distances and sparser instrumentation in the outer regions. MC-studies of array layouts with varying instrumentation density, to yield significant cost savings at improved high energy sensitivity, are

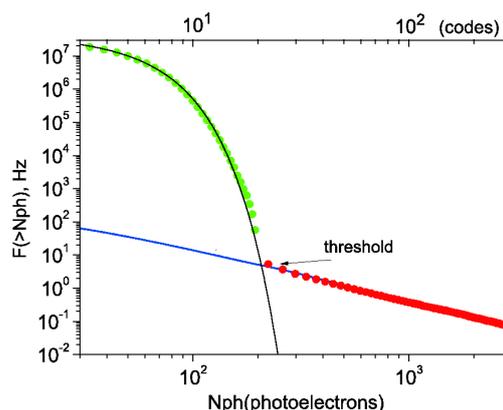


Figure 5: Integral amplitude spectra of Cherenkov light flashes from extensive air showers, measured with a HiSCORE prototype station (2013; red dots), and the estimated NSB-spectrum (green dots). The MC-simulated amplitude spectrum is given as blue curve.

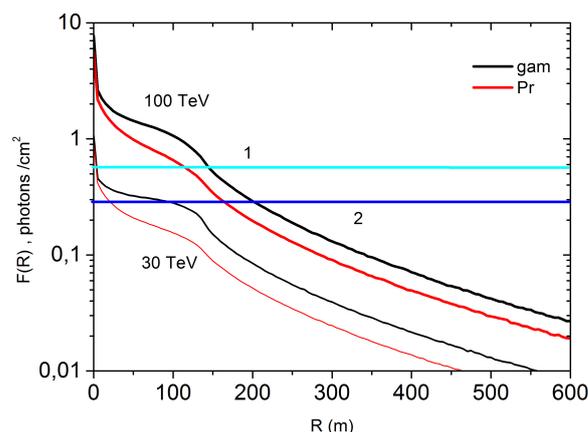


Figure 6: Lateral distribution function $F(R)$ for Cherenkov light from gamma and proton showers (30 and 100 TeV). Indicated are detection thresholds of optical stations: 1 - current, 2 - planned threshold for the 2013 setup.

in progress.

3 Current Status and Plans

In autumn 2012, three HiSCORE prototype stations were installed into the center of the Tunka-133 array. They are arranged at 150 m distance at the corners of a right angle triangle, as shown in [9].

The stations have 4 PMTs (one station has 2 PMTs). Each PMT is equipped with a Winston cone (made of ten segments of ALANOD 4300UP foil, with reflectivity 80%) to increase the light collection area by a factor of 4 [8]. Plexiglass is used on top to protect the PMTs against dust and humidity. For this first prototype setup, the PMT high voltage supply, voltage divider and preamplifiers for the PMT dynode and anode signals follow the Tunka-133 design. As PMT we use the six-stage 8" EMI 9350KB, that has a nominal gain of 10^4 at 1.4 kV supply.

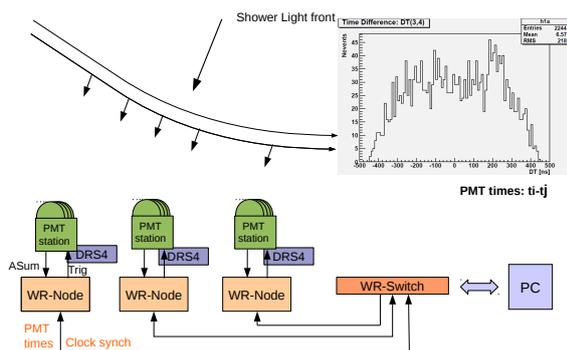


Figure 7: Sketch of the HiSCORE prototype DAQ (2012/13), with focus on the timing/digital triggering system using White Rabbit (WR). Waveforms are recorded by one DRS4-EB per station. Shown (histogram) are time-difference distributions as measured with two stations by the timing system.

The main aim of the prototype stations was baseline functional tests, cross-verification with showers from Tunka-133, and an estimation of the shower energy threshold of the optical station. Figure 5 shows the integral air-shower counting rate for a prototype station, as function of the station trigger threshold (anode amplitude sum). Also given is the trigger rate, calculated from MC (including air-shower simulation, light absorption; blue line). The optical properties of the station (PMT, Winston cone) are considered as an effective quantum efficiency Q_{eff} , found to be 0.06 for the station. The night sky background (NSB) rate is estimated from the pre-trigger fadc-traces (green dots). We derive as station trigger threshold ~ 200 photoelectrons (p.e.). (Note, that in [8] another, more direct threshold measurement is presented.) This yields (with $Q_{eff}=0.06$) a Cerenkov light detection threshold per station of ~ 0.6 photons/cm², as indicated by threshold line (1) in fig.5. The lateral light distribution function in figure 5 shows, that with an improved threshold of 0.3 photons/cm² a detection of γ -ray showers up to 130 m for 30 TeV and up to 200 m for 100 TeV from the shower core is possible. Both improved preamplifiers as well as better PMTs will allow to reach that threshold.

For the DAQ in 2012 we use as baseline the Tunka-133 VME-system (with 200 MHz FADC sampling and 10 ns station time synchronization) [5]. In parallel, we trigger and read out via a HiSCORE prototype DAQ, based on the DRS4-evaluation board (EB), with waveform sampling at 1 GHz, and time-synchronization at sub-ns level with a White-Rabbit (WR) based system (time stamping and triggering) [9].

Waveform sampling and time-stamping proved to be very stable. The ns-trigger timestamps, obtained from the timing system allow clear Cerenkov air-shower detection, see Figure 7 for a sketch of baseline DAQ and WR components. The insert shows the time-differences of Cerenkov signals triggering two stations, giving the characteristic shape of the distribution, in good agreement with the Monte-Carlo predictions (mainly determined by viewing angle and station distance).

In fall 2013, we plan to upgrade the HiSCORE prototype setup to 10 stations (based on 8"-PMTs). They will contain new DAQ-components and improved PMT analog

signal handling. A new, DRS4-based custom DAQ will be operated, as well as a custom made time-synchronization setup being tested. In parallel, the baseline HiSCORE prototype DAQ and timing system, as described above, will be operating. Additional calibration devices will be operated (artificial light sources).

For the midterm future, we plan to build a Tunka-HiSCORE array of about 1 km² size, made of 250-400 PMTs by about 2014. As one option, this could be 64 optical stations with 8"-PMTs on a 150 m grid spacing, later supplemented by another 40 stations of either 8" or 10" PMTs, to lower the energy threshold (see fig.3). Optimization of the array layout is currently ongoing.

4 Conclusions

To open up the window for γ -ray astronomy beyond 20 TeV with a new detection technology, a prototype for the new non-imaging wide-angle gamma-ray detector HiSCORE is currently under construction: the Tunka-HiSCORE detector, located at the site of the Tunka-133 array.

With three first prototype detector stations in operation since October 2012, and an upgrade to 10 stations by fall 2013, it is planned to reach about 1 km² by 2014. Various options for the array layout beyond 1 km² are currently under discussion, for example a denser inner array to minimize the energy threshold.

The non-imaging Cerenkov light detection at Tunka-HiSCORE is planned to be supplemented by small size imaging telescopes (2-3 m² mirrors with 0.05 ster field of view) in future.

In addition, the Tunka-collaboration will install muon counters, to improve gamma-hadron separation and facilitate cosmic-ray composition analysis. The Tunka-site will in the near future turn into a multi-component EAS detector for cosmic-ray studies and gamma-ray astronomy[5].

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