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Tunka-HiSCORE – a new array for multi-TeV gamma-astronomy

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Abstract

Tunka-HiSCORE (HiSCORE – Hundred Square-km Cosmic Origin Explorer) – is a new Cherenkov EAS array for multi-TeV gamma-ray astronomy and CR studies. The array will consist of wide–angle (0.6 ster) optical stations with 150 m distance between individual stations. The array will be constructed in several stages: beginning with a 1 km^2 array at the first stage up to 100 km^2 at the last stage.
The first four stations have been installed during 2012 in Tunka Valley (50 km from Southern tip of Lake Baikal) at the site of the Tunka-133 array. We describe the construction of the optical stations and the array DAQ, and present the first results of common operation of the new optical stations with the Tunka-133 array.

Motivation

We propose to explore the so far poorly measured cosmic ray and gamma-ray sky in the energy region from 10 TeV to 100 PeV with the large area wide-angle cosmic ray and gamma-ray detector Tunka-HiSCORE [1,6]. Tunka-HiSCORE will be a non-imaging Cherenkov light-front sampling array with sensitive large area (0.5 m^2) detector modules, distributed over an array covering a total area of 3.3 km^2.

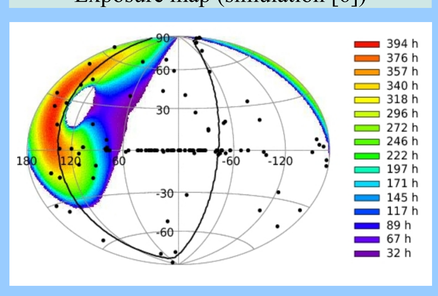
Tunka-HiSCORE array is being developed for the study of fundamental physics questions of astroparticle and particle physics [2,3], including the origin of charged Galactic cosmic rays (gamma-ray observations), spectral and composition measurements of charged Galactic cosmic rays, diffuse gamma-ray emission (e.g. Galactic plane, local super-cluster), attenuation by Galactic interstellar radiation fields and the cosmic microwave background. Existing and planned experiments don't cover the cutoff energy region of Galactic PeVatrons.

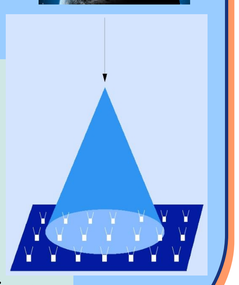
The main area of interest: → Ultra-high energy gamma-ray survey: PeVatron search;
→ Cosmic ray physics from 100 TeV to 1 EeV;
→ Particle physics beyond LHC energy range.

Tunka-HiSCORE project

Gamma-stations (red squares) position relative of the Tunka-133 detectors [4,5] (black circles) are shown. The total number of stations is 172.
Each station is a box with 4 PMTs, slow control electronics, environment sensors, readout and data transmission electronics, and nSec-precision clock.

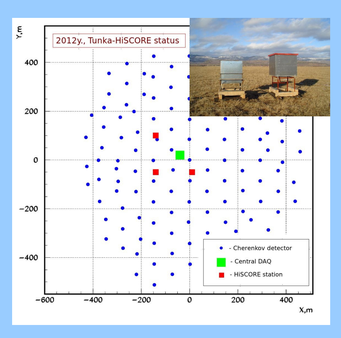
Exposure map (simulation [6])

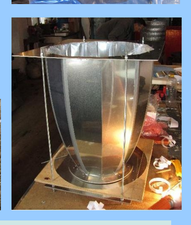




Basic parameters:
- Cosmic Rays: 100TeV < E_{CR} < 100PeV
- Gamma-Rays: E_γ > 10TeV
- Large area: up to 3.3 km^2
- Field of view: ~ 0.6 sr
- Angular resolution (>50TeV): ~ 0.1°
- Flux sensitivity: down to 10^{-12} erg/cm^{2}s
- Concept: non-imaging Cherenkov technique

Tunka-HiSCORE station



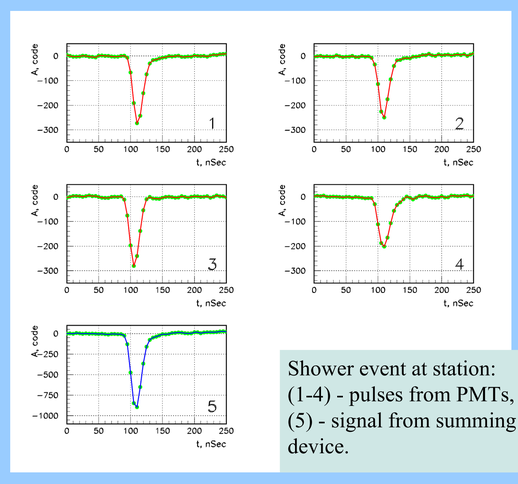


View from above and at the bottom with PMTs.

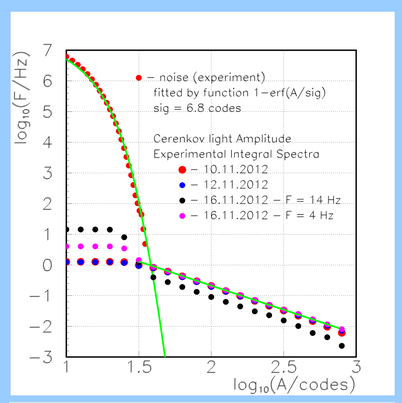
PMT and Winston cone.

A station consists of 4 PMTs each equipped with a Winston cone (ten segments of reflective foil ALANOD 4300UP) that increases the light collection area by a factor of 4. Each cone is mounted on top of a PMT 9352KB. Using a fast pre-amplifier with an amplification factor of 10 results in a sufficient dynamical range of 5 orders of magnitude.
The photo (left) shows the deployment team in front of station number 2 (large box with red cover) and its electronic box.

Measurment results



Shower event at station:
(1-4) - pulses from PMTs,
(5) - signal from summing device.



Integral spectrum of air shower cherenkov light amplitudes.

A Tunka-HiSCORE prototype station measures the faint Cherenkov light that is emitted by extensive air showers which are initiated by ultra high energy cosmic rays and gamma rays. A PMT gain alignment is necessary for the effective summation operation and, as a consequence, allows decreasing the detection threshold of showers.

Data Acquisition System

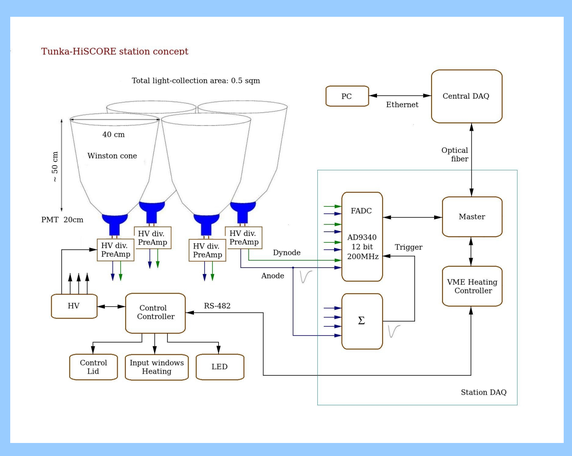


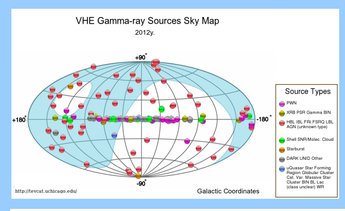
Photo shows a station DAQ : VME crate with Master and FADCs [4] , at a distance - summing scheme.

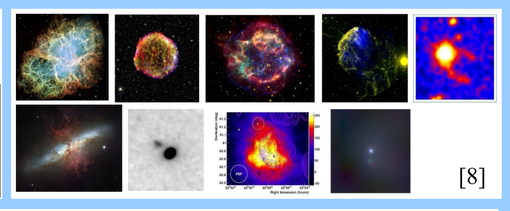
Tunka-HiSCORE station concept is given here (left picture). A six-stage 8" PMT (9352KB) is a nominal gain of 10^4 at 1.4 kV supply. The anodes signals are analog summing (∑) to generate a trigger that is digitized with 5 nSec step as are the signals. Master scheme communicates with the central DAQ, readout and data transmission at presence of a trigger. Data taking and component testing is underway over the winter season 2012/2013.

Outlook

Mechanics: The station mechanics consists of a metal box with a opening/closing lid mechanism. The station will need to tilt for the night star sky survey.
Optics: Each PMT will have a Winston cone with 0.6 m in diameter. Total light-collection area will increase to 1.1 m^2.
Electronics: The anode signals from 4 PMTs will be clipped and summed. Counting rate of air showers from one station must be about 15 Hz.
DAQ: We are assumed to be used a DRS4 chip [7] (or a similar scheme) as a basic element of the DAQ system. The DRS4 chip allows 1024 bin sampling with 0.5-5 Gigasamples/s with a readout rate of up to 500 Hz. The DAQ interface is a Plug mini-PC that transmits event files to a central data server.
Synchro: Synchronization of events between stations will be done with 1 nSec precision by the local clock in each station using optical fiber.
Farther increasing of sensitivity: Using of small mirrors (2 m^2) net with cheap matrix of PMTs or SiPMs for imaging technique.

Gamma-ray sources will be observed

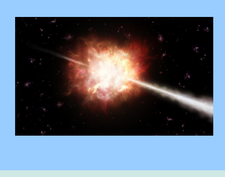




[8]

γ-Source Name	Type	Dist., kpc	$F(1TeV)\times10^{-12}$, $cm^{-2}s^{-1}TeV^{-1}$	$F(35TeV)\times10^{-17}$, $cm^{-2}s^{-1}TeV^{-1}$	T_{obs}, $hours$	N_{obs}, $events$
Crab (SN1054)	PWN	2.0	32.6	162.6	110	680
Tycho (SN1572)	Shell	3.5	0.17	–	236	88
Cas A (G111.7-2.1)	Shell	3.4	1.26	–	177	40
MAGIC J0616+225 (IC443)	Shell	1.5	0.58	28.8	112	2÷50
Geminga (MGRO J0632+17)	PWN	0.169	–	37.7	102	80
M82 (NGC3034)	SBG	3900	0.25	–	325	22
Mrk421 (1H 1104+382)	HBL	130000	50÷200	–	140	~8950
Boomerang (G106.3+2.7)	PWN	0.8	1.42	70.9	167	187
CTA 1 (G119.5+10.2)	PWN	1.4	1.3	–	266	200

PeVatron detection !?



Expected parameters:
Area: ~1 km^2
Stations: 64
PMTs: 4 in 1 station
Energy threshold: ~25TeV
Sensitivity: ~10^{-12} erg/cm^{2}s
Observation time: T_{obs}
Gamma-ray events: N_{obs}

Conclusion

- The first Tunka-HiSCORE prototype station containing two Winston cones and two PMTs was deployed on the Tunka-133 cosmic-ray observatory, Siberia, in April 2012.
- Three stations were commissioned in October 2012, two of which consists of 4 PMTs with cones.
- Data taking, testing of station components and data analysis are carried out in the season 2012/2013.
- Necessary decreasing of the energy threshold, as a local single-station cosmic-ray trigger rate must be ~ 15 Hz.
- Necessary increasing the area of the array to 1 km^2 and more.
- Large field of view station, as the array will simultaneously scan a large fraction of the night star sky (survey mode).
- An international collaboration was started and leaded to prototype deployment in the Tunka valley.

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