The gamma-observatory TAIGA: design, status and preliminary results.

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TAIGA (Tunka Advanced Instrument for cosmic rays and Gamma - Astronomy)

Location:
Tunka Valley, Republic of Buryatia, 50 km west from Lake Baikal

The main aim of the TAIGA project:
study of very high energy (>30 TeV) gamma rays from Galactic accelerators with large area array (~10 km²)
All installations in Tunka Valley and TAIGA

1. Tunka-133
2. Tunka-Grande
3. Tunka-REX
4. TAIGA-HiSCORE
5. TAIGA-IACT
6. TAIGA-MUON

All installations are synchronized via optical cables with 10-ns accuracy
# TAIGA - collaboration

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1. High energy gamma-ray astronomy and TAIGA project

2. TAIGA current status

3. The experiment in future
1. High-energy gamma-astronomy and the TAIGA project
The TAIGA experiment is a hybrid detector for very high energy gamma-ray astronomy and cosmic ray physics in the Tunka valley.

The main idea: A cost effective approach for construction of a large area installation is a joint operation of wide-field-of-view timing Cherenkov detector (non-imaging technique) with a few small-size imaging Air Cherenkov Telescopes.

The first stage of TAIGA - 1 km² area installation with 120 wide-angle timing detectors and 3 IACTs. Commissioning of installation in 2020.
Scientific Program

1. Study of high-energy edge of spectrum of galactic gamma-ray sources. Search for Pevatrons

2. Monitoring of the bright extragalactic sources

3. Apply the new hybrid approach (joint operation of IACTs and wide-angle timing array) for study of cosmic rays mass composition in the “knee” region (10^{14} - 10^{16} eV)

4. Fundamental physics (photon-axion oscillation, indications of Lorentz invariance violation etc).
Wide angle station of TAIGA-HiSCORE

- 54 optical stations (at present)
- 106 m interstation distance
- Tilted to the south by 25 deg
- 4 large area PMTs with 20 or 25 cm diameter (EMI ET9352KB and Hamamatsu R5912 or R7081)
- Winston cone with 40 cm diameter and 30 deg viewing angle (FoV \(\sim 0.6\) sr)
- \(S = 0.5\) km\(^2\)
Angular resolution

- ~0.4-0.5 deg for 4-5-station events
- ~0.1 deg for more than 10-station events
Common observation of ISS LIDAR by TAIGA-HiSCORE and optical telescope MASTER

Absolute pointing of HiSCORE $\alpha_{\text{miss}} \sim 0.1^\circ$
Energy peak (threshold)

Experimental spectra for hadrons

Energy peak for hadrons

≥ 3 stations ~80 TeV
≥ 4 stations ~100 TeV

Energy peak for γ

≥ 3 stations ~40 TeV
≥ 4 stations ~50 TeV
Reflector:
- Davies-Cotton design
- 29 glass-mirror tiles of 60 cm diameter
- Diameter: 4.32 m
- Focal length: 4.75 m

Camera:
- 560 PMTs: XP 1911, 15-mm photocathode
- Winston cone: 30 mm input size, 15 mm output size aperture single pixel ~0.36°
- FOV: ~9.6°

Energy threshold ~1.5 TeV
Camera of the TAIGA-IACT

- PMT + Winston cone
- 560 PMTs
- Signal processing based on MAROC3

MAROC3 64-channel board

28 PMTs
Cluster

- PMT gain: $\sim 10^5$
- Anode current: $\sim 2 \mu A$
- 4 groups of 7 PMTs
- HV power supply, HV dividers for each group
- Control board based on the 64-channel chip ASIC MAROC3 (MAROC board)
- PMT signal splits into 2 channels with different PA gains to increase dynamic range up to 3000 p.e.

**MAROC board**
- Signal processing
- Data acquisition
- Cluster trigger
- Monitoring of counting rates
- DC anode currents
- HV control
Controllers

DAQ-controller (central controller)

- 24 input: data
- 24 input: triggers from MAROC boards
- Data rate ~30 Mbit/sec on Xilinx Spartan-6
- Controller provides data transmission up to 5 kHz for 4-5-cluster events

Power controller

- +12 V to MAROC boards
- +24 V to HV power supplies
Cluster trigger

- The same threshold ~10 p.e. for all channels
- ≥ 2 triggered pixels within ~15-ns window
- Integration time ~40 ns
- Hold-signal after ~50 ns
- External ADC

Camera trigger

- Cluster trigger comes to the central controller (CC)
- CC polls another clusters in 160-ns window, clusters with at least 1 triggered pixel are also recorded to event
- Deadtime ~180 us, at count rate of 1 kHz registration efficiency ~83%
Distance and core position

- MC events
- $E_\gamma > 30$ TeV
- Center of gravity of images is inside the circle with a radius of 3.5 degrees at core position up to 600 m
Clusters of the first camera

- 560 pixels
- 22 clusters
- Data analysis selects events with center of gravity inside the circle with a radius of 3.5 degrees
LED calibration

- \( R = 2.36 \times \sqrt{F} / \sqrt{N_{pe}} \), where \( F = 1.3 \)

Nanosecond pulsed LED
Relative sensitivity of pixels

2 pixels with known QE

σ ~ 17 %
(different PMT responses, amplitudes)

PA gain compensates the difference

Same registration efficiency of pixels
The telescope tracked a bright star.

Inside the camera a calibration screen is installed in the telescope focus.

A spot from the star can be seen on the CCD-camera image on the screen.

PSF $\approx 0.07$ deg
(1 2D Gaussian sigma)
2. TAIGA current status
HiSCORE station

- 4 PMTs of 8" size with Winston cones (light collection 0.5 m²)
- FoV ~0.6 sr

54 detectors, 106 m spacing, S~0.5 km²

Current status

IACT
- S of mirrors: 8.5 m²
- Focus: 4.75 m
- FOV: 9.5°
- One pixel: 0.36°
- 560 pixels (in 22 clusters)
- PSF: ~0.07°
- CCD for checking telescope pointing direction

900 m
CR energy spectrum 2018

\[ I \times E_{0}^{2.7}, \text{(m}^{-2} \cdot \text{sec}^{-1} \cdot \text{ster}^{-1} \cdot \text{eV}^{1}) \]

\[ \lg \left( E_{0}/\text{eV} \right) \]

\[ \chi = -2.73 \pm 0.01 \]

\[ \chi_{2} = -3.18 \pm 0.03 \]
$\Psi^2$ – joint event distribution

EAS direction

Telescope axis

HiSCORE events

Effectivity $\sim 95%$

Effectivity $\sim 50%$

$\Psi = 3.6$ deg

$\Psi = 4.7$ deg
Example of hybrid gamma-like event

IACT data
Width=0.13°, length=0.69°, alpha=8.9°, size=709 p.e.

HiSCORE data
E = 55 TeV
Tet = 32.9 deg
Fi = 33.58 deg

Recalculated core position in IACT plane after introduction of scaling factor $R_p' = R_p/1500$
3. The future of experiment
Plan for 2019-20

- For 100 hours
- $3 \cdot 10^5$ hybrid events (CR mass composition)
- 50-100 hybrid events from Crab ($E \geq 40$ TeV)

110 stations

Mirrors in July and camera in September 2019
Long term plan for TAIGA

- **1000 wide angle optical station** on the 10 km² area, energy threshold 30 TeV

- **10-15 IACTs** (10 m² mirrors).

- **Muon detectors** with total area $3.0 \times 10^3$ m².

Installation should be placed at 2000 m u.s.l.
HiSCORE and IACT – only 1% of joint events

We need to increase FOV of camera to 60° the same as HiSCORE. The first step is camera with FOV ~ 15-20°

1. Spherical Mirror
2. Corrected lens
3. Focal surface

Wide-angle telescope on SiPMs

- FOV ~ 15-20°
- S ~ 1 m²
- Number of pixels ~ 1000-1200
- FOV for one pixel ~ 0.4°
- Energy threshold ~ 10 TeV
Conclusion

1. TAIGA - 10 km$^2$ hybrid array 1000 wide-angle stations and 15-20 IACTs). The sensitivity for local sources in the energy range 30 -200 TeV is expected be $10^{-13}$ TeV cm$^{-2}$ sec$^{-1}$ (for 500 h observation)

2. Deployment of the full scale TAIGA prototype -110 wide-angle stations and three IACTs is planned for 2019-2020. The expected sensitivity for 300 hours source observation with this array in the range 30 – 200 TeV is about $2.5 \times 10^{-13}$ TeV/(cm$^2$ sec) (~0.1 Crab), 50-100 hybrid events from Crab per 100 hours

3. The first commission seasons were successful:
   - CR energy spectrum below the knee
   - Lidar on board ISS – light calibration source for TAIGA
   - First results from joint operation of HiSCORE and IACT

4. Work has begun on the creation of new cameras based on SiPM
Thank you