THE FIRST SEASON OPERATION OF HYBRID IMAGING / TIMING CHERENKOV ARRAY TAIGA

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Tunka Valley

26th ECRS & 35th RCRC Barnaul/Belokurikha, Russia
The TAIGA experiment – a hybrid detector for very high energy gamma-ray astronomy $E_g > 50\text{TeV}$ and cosmic ray physics in the Tunka Valley

**Main ideas** common operation of wide-field-of-view timing Cherenkov detectors (the non-imaging technique) with a few relatively cheap, small-sized imaging Air Cherenkov Telescopes.

HiSCORE (High Sensitivity Cosmic ORigin Explorer)

The first stage of TAIGA – 1 km² area installation with 100 wide-angle timing detectors and 3 IACTs. Commissioning the installation in 2019
HiSCORE measures:
1) The arrival direction – by the time delay: accuracy 0.1–0.4°
2) The core position by the LDF function: accuracy 5–30m
3) The energy by Q at 200m: accuracy 20-40%
3) Energy threshold $\tilde{E}$ 100 TeV (CR) and ~50 TeV (gamma-rays)

Non-IACT technique was developed for Tunka-25 and Tunka-133 arrays for cosmic ray detection and was optimized for PeV–100 PeV energy. To move to sub-TeV region, special high sensitive detectors were developed. In 2014-2017 the exposure of the first 28 stations confirmed the possibility to reach as low energy as 100 TeV.
The IACT technique was developed and optimized for energies around 1 TeV. Typical design: system of Cherenkov telescopes with 150 m inter-telescope distance, each of them has a mirror, a camera with a field of view of the order of 4 degrees. γ-ray detection for higher energy requires larger effective area and sufficient number of telescopes (CTA)

**IACT functionalities (using the image parameters):**

1) Arrival direction and core position by stereo technique
2) Energy by the image size
3) Effective background rejection
SEASON 2017-2018: LAYOUT PARAMETERS

HiSCORE stations: 43
(current layout)
“Tilting” to the South at 25°

Sub-ns array-wide
time synchronization

43 detectors, 106 m distance,
S~0.5 km² (Only green stations
were included in analysis)
S~0.25 m²

IACT: 1 (current layout)
S of mirrors 8.5 m²
Focus 4.75 m
FOV 9.5°
Accuracy
of tracking 0.05°
(poster of D.Zhurov)

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

N.Budnev. ‘TAIGA status’, This conference
**IMAGING CAMERA**

**Camera:**
- 560 XP1911 PMTs, D=15 mm
- Winston cones: D=30mm, FOV 0.36°
- Full FOV: 9.5° diameter

PSF ~ 0.14° - 0.17°

The camera has modular structure 22 clusters. The basis of the readout electronics of a single cluster is a 64-channel ASIC MAROC 3. Each channel includes a preamplifier with the adjustable gain, charge sensitive amplifier, and a comparator with the adjustable threshold. The chip has a multiplexed analog output with a signal proportional to the input charge. Signals from each PMT go to 2 channels with preamplifier gains different by a factor of 4. This results in the full dynamic range of 3000 photoelectrons (p.e.).

**Trigger conditions:** Amplitude in 2 PMTs in one cluster exceeds the threshold (8p.e. – 10 p.e.) within the 15 ns period
Main idea of the approach: To combine information, obtained from Hiscore data and IACT data.

Cherenkov image is characterized by Hillas moment analysis. Major axis of ellipse is described by the length and width parameters. Its location – by ‘Dist’ and orientation within the FOV are given by alpha parameter.
Recalculated core position in IACT plane after introduction of scaling factor $R_{p'} = R_p/1500$

First example of hybrid "gamma-like" event

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

HiSCORE data

- $E = 55$ TeV
- Tet = 32.9, Fi = 33.58

IACT data

- $\text{Width} = 1.6 \text{ cm, } \alpha = 8.8 \text{ deg}$

Width = 0.13°, length = 0.69°, alpha = 8.9°, size = 709 p.e.
MAIN TASK FOR THIS YEAR WORK – TO UNDERSTAND TELESCOPE DATA

- check the efficiency of common analysis
- estimate the energy and size thresholds
- tuning of MC (Monte-Carlo simulations)
STEPS OF IMAGE DATA ANALYSIS

1 step: Summarize amplitudes from different clusters and subtract pedestals
2 step: Transform ADC codes to photoelectrons, introduce corrections to sensitivity
3 step: Anode current analysis:
   a) background control
   b) bad pixels removal
   c) star tracks removal
6) Cleaning procedure to remove NLB
7) Visual image analysis to remove fake events
9) Calculation of Hillas parameters

Number of hit clusters ~ size of event

5 hours of observation

NBL

Coamac rays

Fake events
Experimental integral size spectra, obtained in 3 days in standalone mode of operation & MC

The primary spectrum of all particles and Pr+He similar to the spectrum of Horandel x1.2

Expected threshold for protons 4\pm 1 TeV
for gamma-rays 2\pm 0.5 TeV

With uncertainty 25% we reproduce spectrum of sizes:
Size_{exp}=\sim 0.75 \times \text{Size}_{MC}
In the first approximation, MC simulations reproduce Hillas parameters of background events and size spectra.

See also poster E.Postnikov “Monte-Carlo for TAIGA ..)”
THE STANDALONE MODE MONITORING OF “TEST” GAMMA-RAY SOURCES (CRAB, MRK-421) BY THE IACT

Expectated observation time with good weather:
Crab - 130 hr ~25hours
Mrk-421 - 120 hr ~ 25 hour
Tycho - 190 hr

Due to abnormally bad weather during this season and a number of technical problems, the monitoring time of the "test" gamma sources (Crab, Mrk-421) was only about 25 hours,

~1.2x10^6 events
# Statistics of Hybrid Coincidence Events

<table>
<thead>
<tr>
<th>Description</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>IACT only: effective time 25 hr, Size&gt;80 pe., Npix&gt;4</td>
<td>~100000</td>
</tr>
<tr>
<td>HiSCORE only Ndet ≥ 4, (0.25 km²)</td>
<td>1.33 · 10⁶</td>
</tr>
<tr>
<td>IACT + HiSCORE joint events</td>
<td>17000</td>
</tr>
<tr>
<td>Expected number of joint events (in IACT FOV)</td>
<td>15000</td>
</tr>
<tr>
<td>Joint events out of IACT FOV (gam&gt;5°)</td>
<td>2000 d</td>
</tr>
<tr>
<td>Hiscore + IACT in the Crab direction gam&lt;1°</td>
<td>212</td>
</tr>
</tbody>
</table>

Big difference in number is caused due to difference in time
due to difference in aperture
due to difference in effective area

Distribution by Tiact -THiscore
ANGULAR EFFICIENCY OF REGISTRATION FOR JOINT EVENTS

- Effectivity ~95%
- Effectivity ~50%
- Angle between IACT axis and shower arrival direction, measured by HiSCORE
- Leakage plot with HiSCORE events

- Gam = 3.6°
- Gam = 4.5°
- Gam = 6.3°
INTEGRAL SPECTRA BY SIZE FOR THE IACT EVENTS AND JOINT EVENTS

Monte Carlo
\[ E = 3-1000 \text{ TeV}, \quad g = -2.6 \]

Joint events

\[ N(>\text{size})/t, \text{ sec}^{-1} \]

Size, ph.el.

Integralspectra by size

Experiment IACT

\[ \begin{align*}
\text{only IACT} & \\
\text{161117 IACT} & \\
\text{281017} & \\
\text{141117} & \\
\text{Joint events} & \\
\end{align*} \]

HiSCORE energy spectra In linear scale

Peak energy
\[ \sim 100 \text{ TeV} \quad \text{– CR} \]
\[ \sim 50 \text{ TeV} \quad \text{– gamma} \]
Size dependence on distance between IACT and shower axis in shower plane for various energies: 50-100 TeV, 100-300 and 300 -1000 TeV

\[ \langle E \rangle = 80 \text{ TeV} \quad \langle E \rangle = 500 \text{ TeV} \]

Size, p.e.

\[ R_p, \text{ m} \]

Red points \( \bullet \) denote LDF

Extrapolation from LDF at 80 TeV to LDF at 4 TeV and 2 TeV for protons and estimation of LDF for gamma \( \sim 2 \text{ TeV} \)

\( E_\gamma (\text{TeV}) \sim 100 \text{ p.e./100 up to } R_p=150 \text{ m} \)

Rough estimation !!!
COMMON ANALYSIS OF ARRIVAL DIRECTION: FROM HISCORE DATA AND FROM IMAGE ANALYSIS
PROJECTION OF SHOWER AXIS ON CAMERA PLANE FOR EVENTS WITH GAM < 1°
ESTIMATION OF ARRIVAL DIRECTION BY ‘DISP’ METHOD AND COMPARISON WITH ARRIVAL DIRECTION FROM HISCORE (‘GAM’)

Mean Gam-θ_{disp} = 0
RMS 0.35 °
MC simulations after tuning successfully describes Hillas parameters for different intervals of Size and distance.

Q~3 at eps~0.6
GAMMA-LIKE EVENTS

Gam – the angle (the direction at the Crab, the shower direction by HiSCORE)

Effective Time – 25 hours
Full number of events with Gam <1° 255 events
Criteria for Hillas parameters:
width < 0.16, alfa < 18° 7 events
dist <3.2° 3 events

Energy gamma ~ 50-60 TeV
Distances ~ 50 m, 299 m, 270 m

Expected number with energy Eg>50 TeV ~ 5-10 events
According to the results of the first IACT full operation season (with all mirrors installed and in the source-tracking mode), we can draw the following conclusions:

1. Experimental Hillas parameters (width, length) are in good agreement with MK

2. The energy threshold of the telescope for hadron EAS for zenith angles of 30-40° is approximately equal to 4 TeV (2 TeV for EAS from Gamma quanta), which corresponds to the expected value.

3. Due to abnormally bad weather during this season and a number of technical problems, the monitoring time of the "test" gamma sources (Crab, Mrk-421) was about 20 hours, instead of the expected 100-120 hours. The first results of monitoring these sources will be presented later.

4. An experimental bank of hybrid events is created – 15,000 events. The effectiveness of HiSCORE events detection in the FOV of the IACT is close to 100%. The main characteristics of the hybrid events are in good agreement with the MC.

By 2019, TAIGA will include 100 wide-angle stations on an area of 1 km² and 3 IACTs.
PLAN FOR 2018-19

100 stations

For 100 hours

$3 \cdot 10^5$ hybrid events
(CR mass composition)

50-100 hybrid events from Crab ($E \geq 0.40$ TeV)
MONITORING OF “TEST” GAMMA-RAY SOURCES (CRAB, MRK-421) BY THE IACT IN THE STANDALONE MODE

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~1.2x10^6 events

The first results will be presented after 50 hours of observation for the low-energy region and after 100 hours of observation for hybrid events.
THANK YOU FOR ATTENTION!
Expected number of excess events for 25hr,0.25km2)
Eg>50 TeV ~ 3-10 events