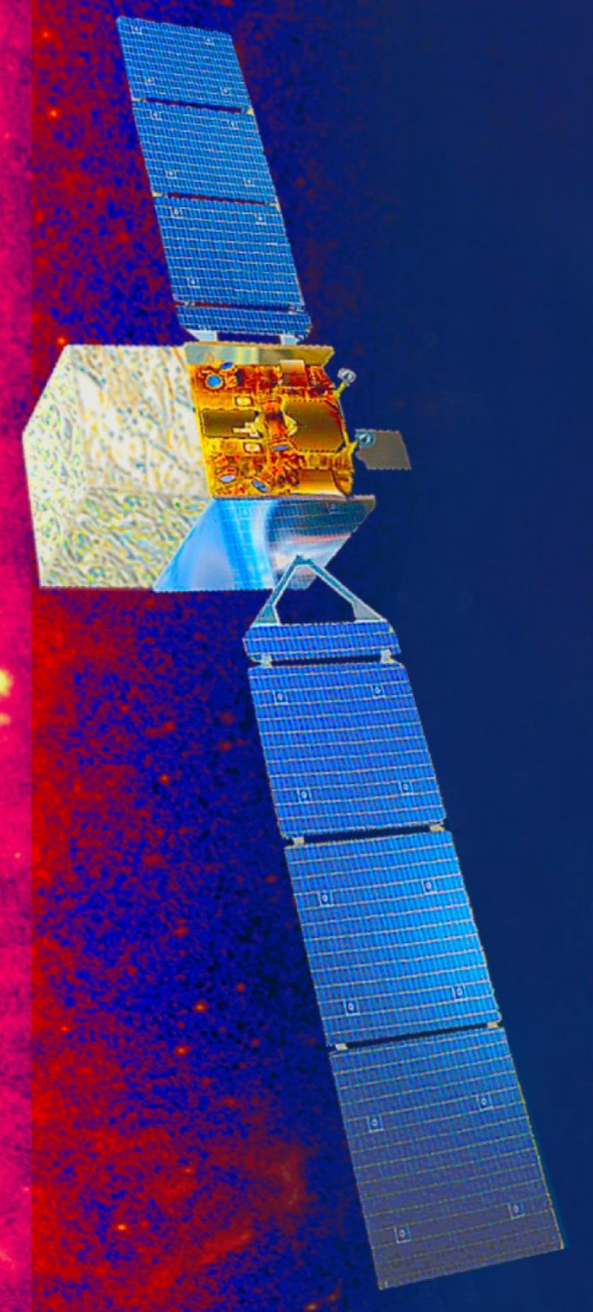
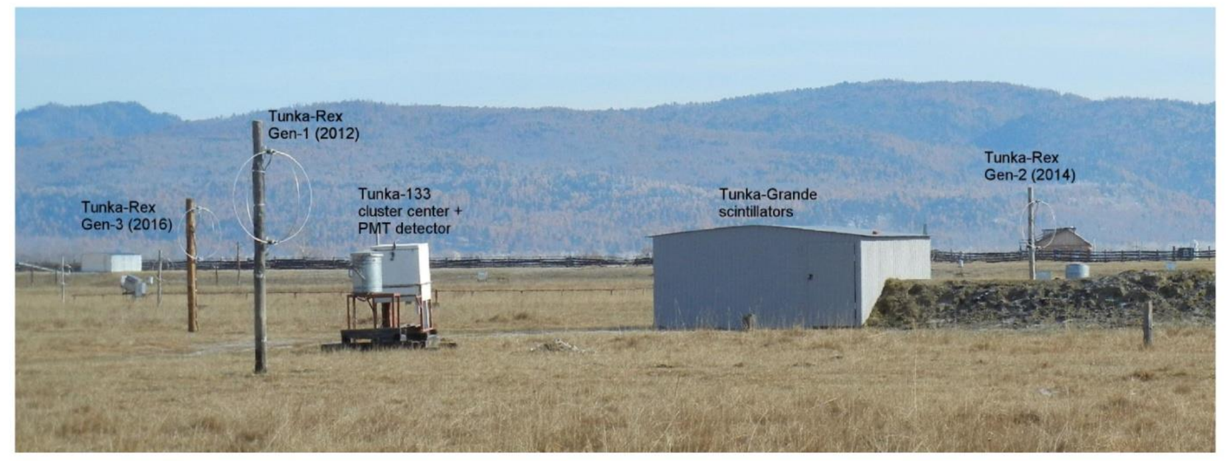
7th International Fermi Symposium

НИИЯФ МГУ

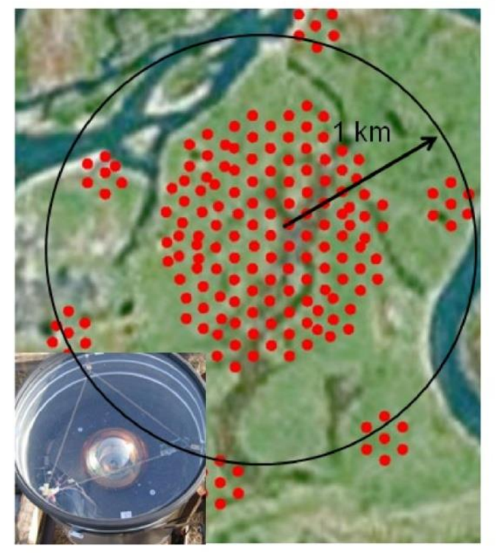


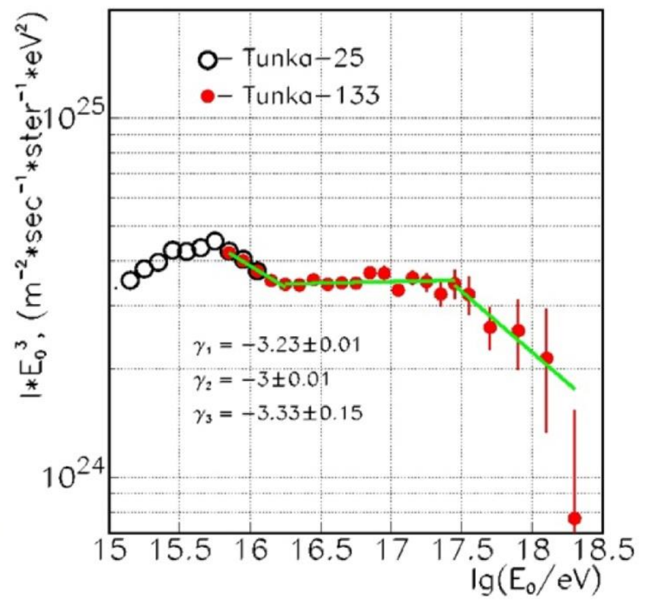
TAIGA history



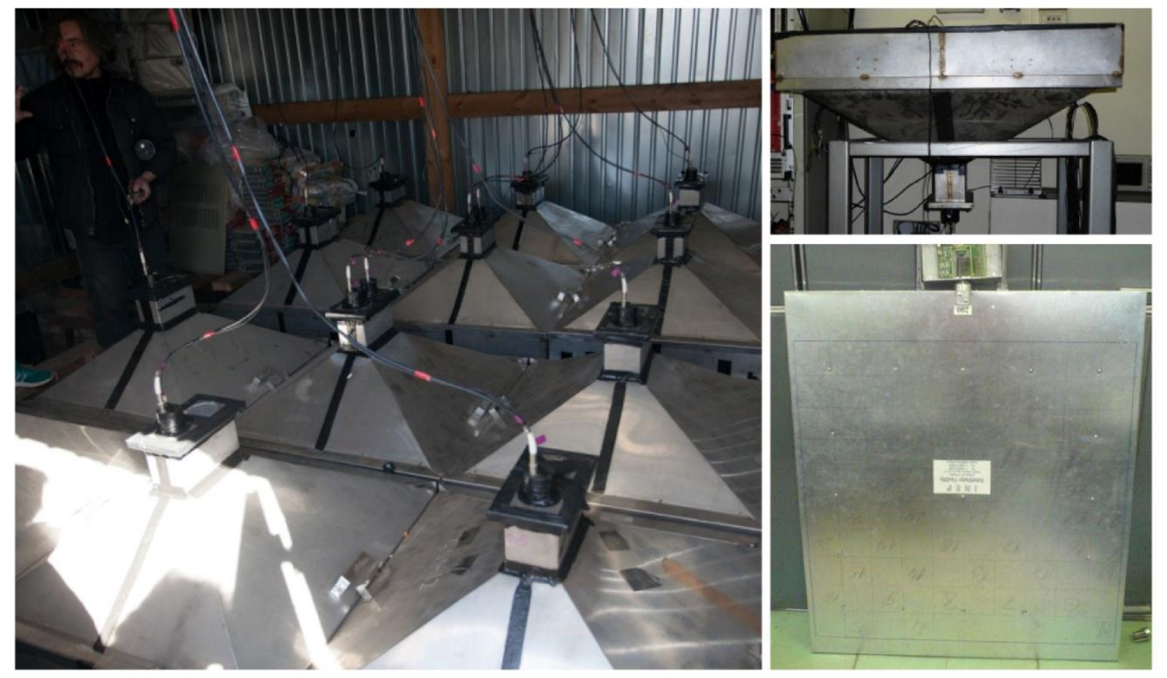
TAIGA (Tunka Advanced Instrument for cosmic ray physics and Gamma-ray Astronomy, where Tunka means Tunka Valley near Lake Baikal, and it's really located in the *taiga* region of Siberia) was founded in the 2000s. It's brief history can be described as follows:

- 2009: the array of 133 PMT detectors (Tunka-133) was inaugurated (UHE cosmic rays above 0.1 EeV).





- 2012: the radio EAS array Tunka-Rex started deployment in the frame of a Helmholtz-Russia Joint Research Group. Currently it has 63 antenna stations distributed over the whole area of Tunka-133 for the UHE CR radio measurements at any time of the day in the same energy region as Tunka-133.
- 2012: TAIGA-HiSCORE was put in operation with the same detection principle as Tunka-133, but featuring more sensitive and accurate PMT detectors (currently 0.4 km² area, VHE CR >40 TeV).
- 2014: Tunka-Grande was built – 19 scintillation stations with an area of 13 m² each (taken from EAS-TOP and KASCADE-Grande, but featuring new DAQ) for the EAS electron and muon measurement simultaneously with the radio antennas of Tunka-Rex and the PMTs of Tunka-133.



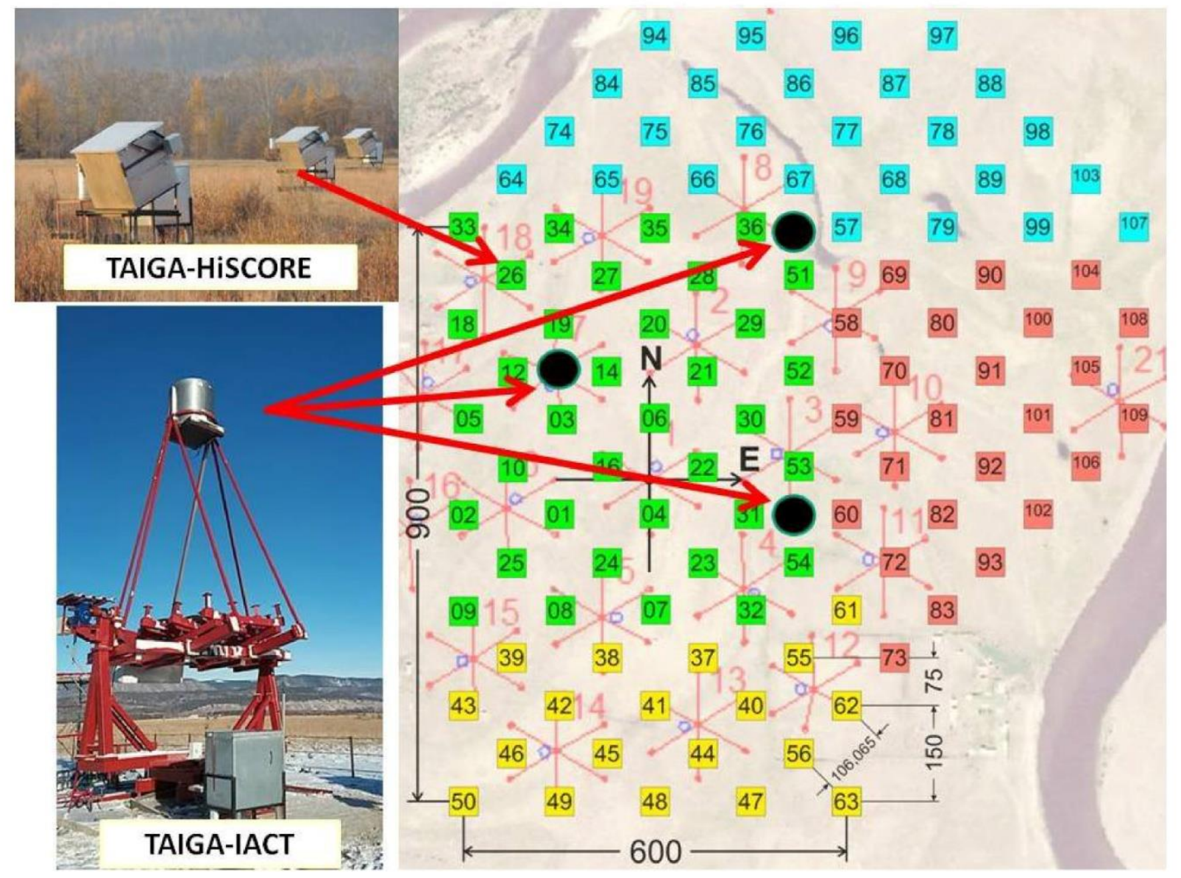
- 2015: the first IACT is under construction to study VHE γ-rays in addition to VHE & UHE cosmic rays.
- 2016: commissioning the first IACT prototype with 6 mirrors installed, first images received (12/2016).

- 2017: installing 29 mirrors of the IACT (09/2017), coming into full operation.

TAIGA in 2018–2019

Summary of the TAIGA development plans for the next two years:

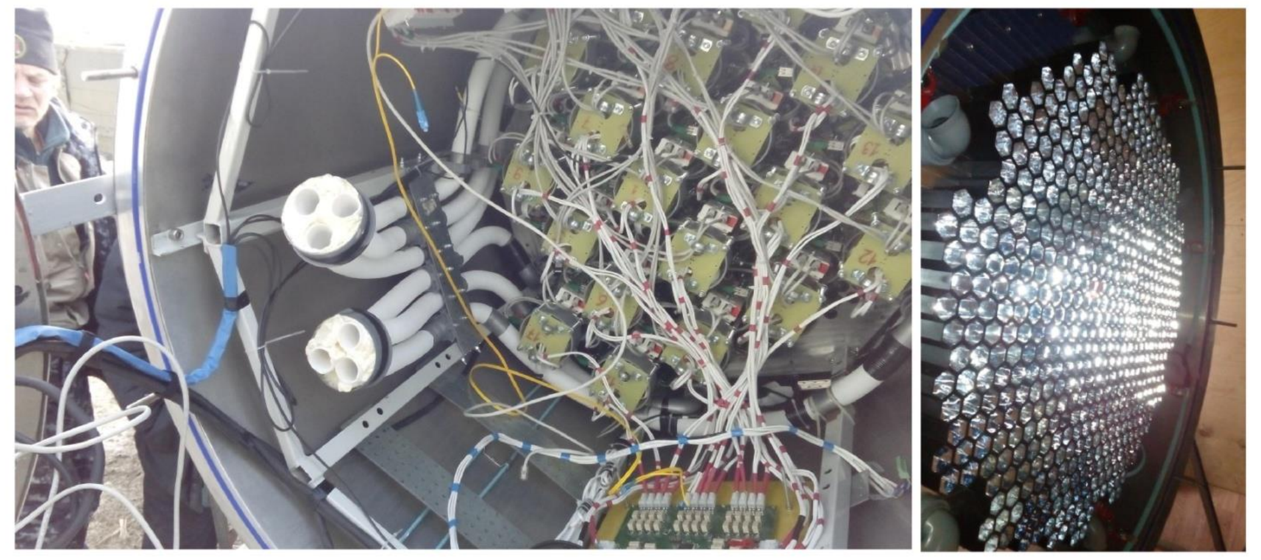
- Commissioning the 2nd IACT (2018) and the 3rd one (2019) in addition to the first one with the same parameters.
- Expanding wide angle Cherenkov timing array up to 110 detector stations (FOV 0.6 sr each) for covering 1 km² area (and later 5 km² area).
- Installing the array of muon detectors of ~200 m² size for covering 1 km² total (and then up to ~3000 m² size).
- Discrimination of γ-ray events originating from the Crab Nebula, Markarian 421, and Tycho's SNR against CR background.



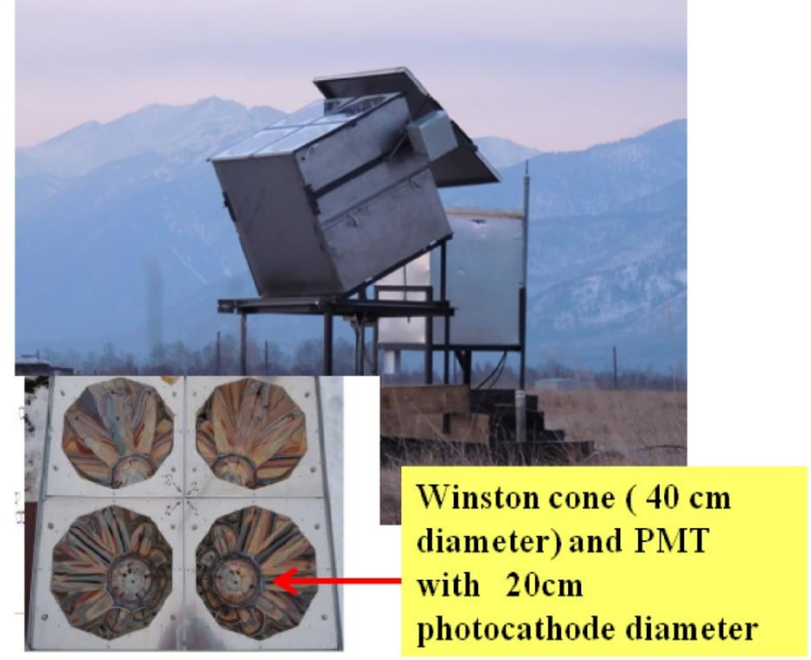
TAIGA parameters

Basic parameters of the TAIGA installation and constituent detectors:

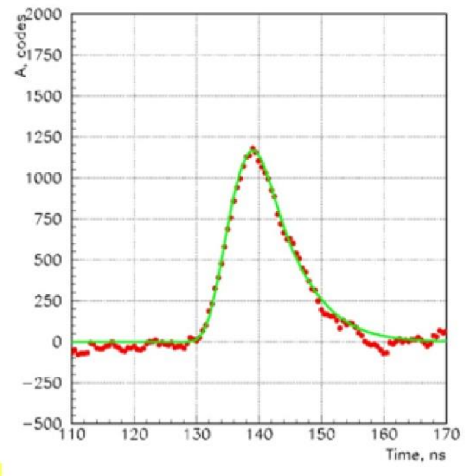
- Location: 51°N 103°E (the northernmost & polarmost IACT of the world).
- γ-ray low energy threshold: ~40 TeV (IACT + timing array), ~2–3 TeV (IACT only).
- Effective area: 0.4 km² currently, 1 km² in 2018–2019.
- The expected integral sensitivity: ≈2.5x10^{-13} TeV/(cm²sec) for 300 hours of a source observation (2 seasons of operation) at 100 TeV.



- IACT parameters:
  10 m² mirror;
  10°x10° field of view;
  ~550 PMTs/camera;
  22 64-channel DAQ boards, each based on MAROC3 ASIC;
  integration time 35 ns;
  effective radius of EAS detection ~600 m (IACT + timing array).



Winston cone (40 cm diameter) and PMT with 20cm photocathode diameter



Digitization of signal by DRS4 board with 0.5 ns step

- Timing array parameters:
  0.6 sr field of view of one detector station;
  4 PMTs/station;
  inter-station distance >106 m;
  total number of stations – 43 (for now), ~110 (in 2018);
  stations direction: South (25°) for the Crab observation;
  measurement precision:
    energy ~15–20%,
    shower arrival direction ~0.1°–0.4°,
    shower core position ~10–15 m.

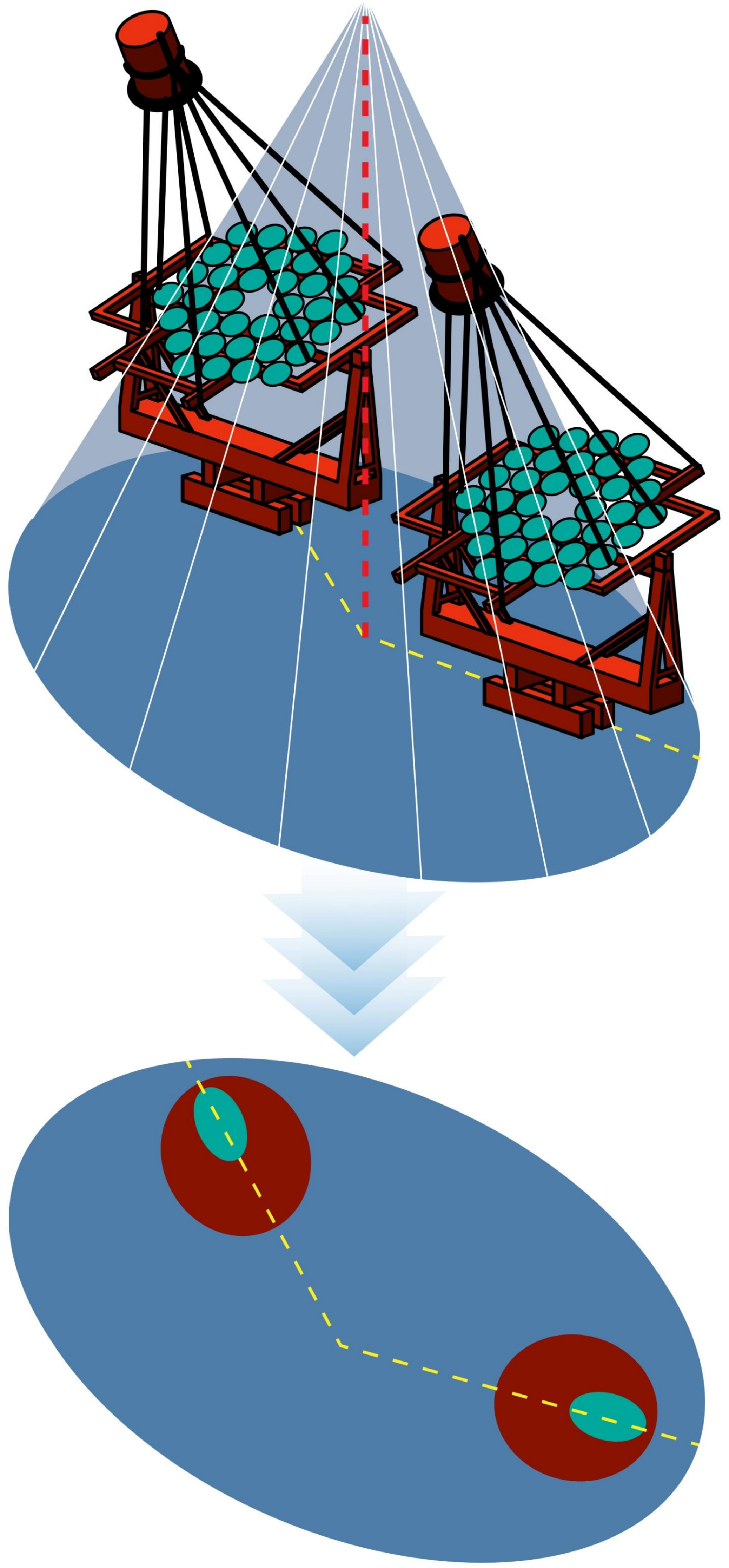
TAIGA

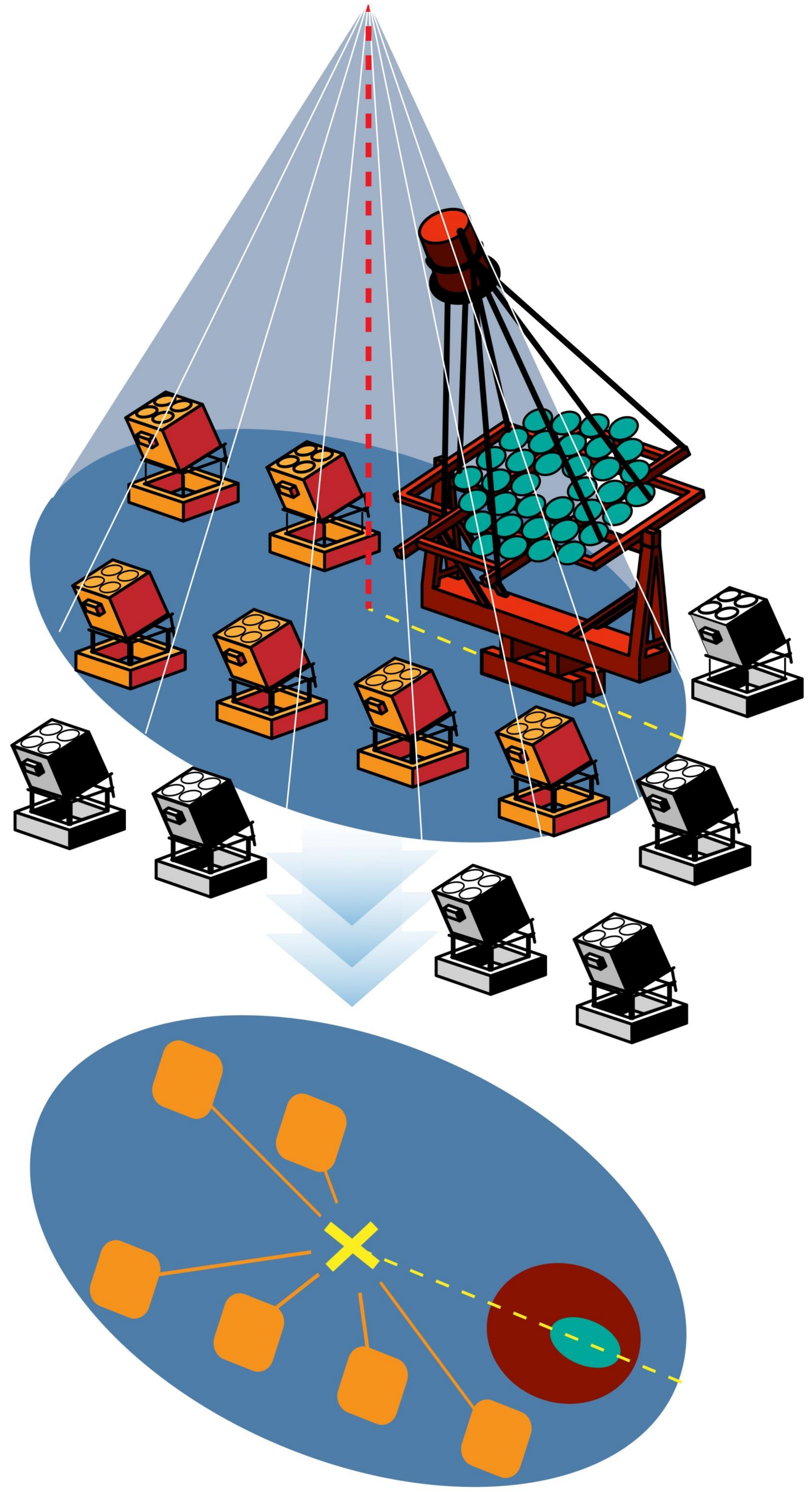
TAIGA principle of operation

TAIGA principle of operation is different from stereoscopic operation of a few IACTs as well as from monoscopic operation of a single IACT.
Instead, it's rather a combination of mono and stereo regimes within a hybrid approach, when information from the 2nd telescope is unavailable (because it is located at a large distance from the 1st one or is absent at all), but is replaced by the same information from the timing array. Therefore, 'IACT + timing array' now works instead of 'IACT + IACT'.

Stereoscopic operation of IACTs <u>(standard approach)</u>.

Inter-IACT distance ~100–150 m





Combined operation IACT + timing array <u>(TAIGA approach)</u>.

Inter-IACT distance may be increased to ~600–800 m

TAIGA

7th International Fermi Symposium

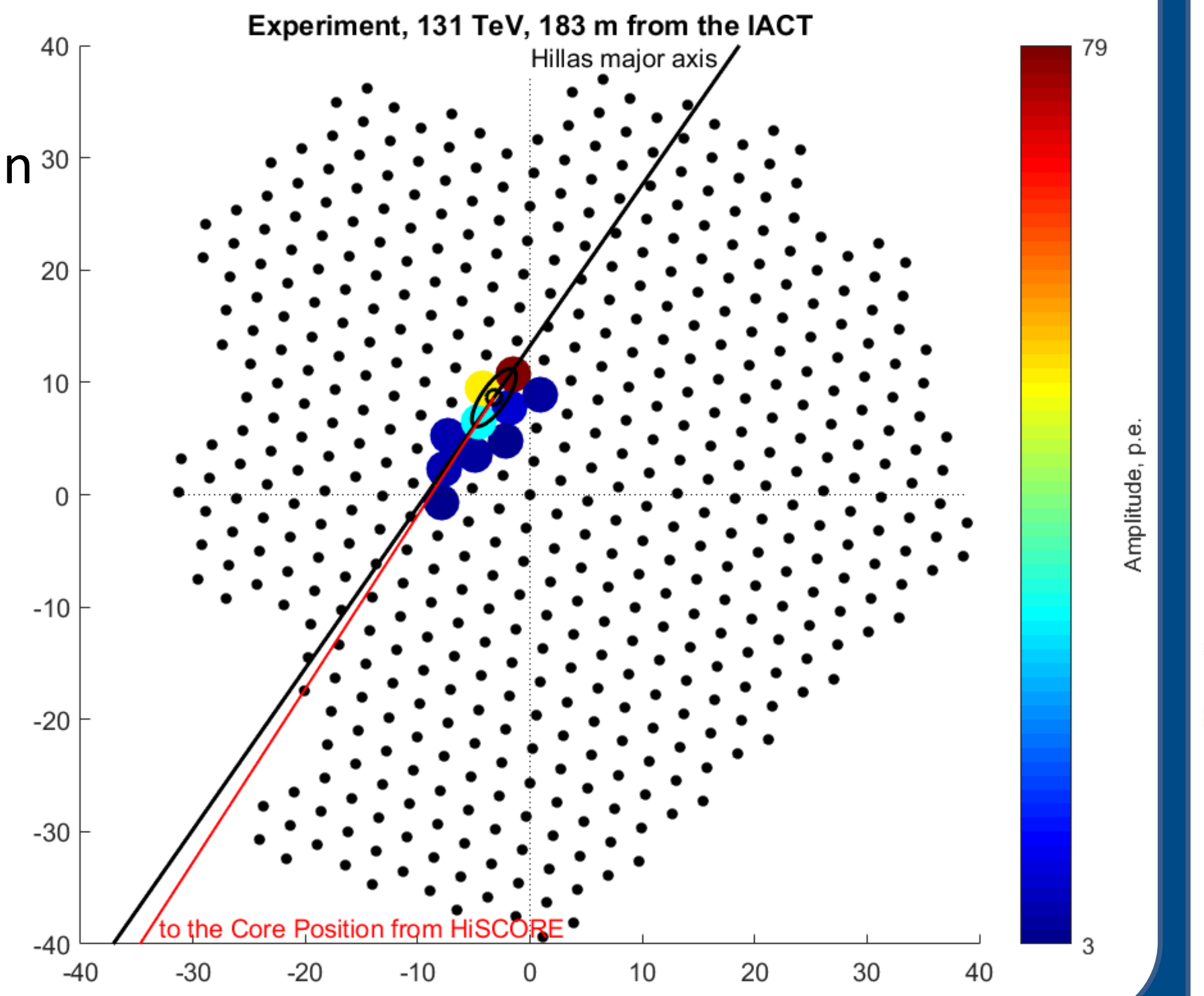
НИИЯФ МГУ

TAIGA-IACT first data

EAS count rate of the first IACT prototype with 6 mirrors installed is 5x10^5 events per night. Part of these events (10^4 per night) was detected also by the timing array – 'joint events'.

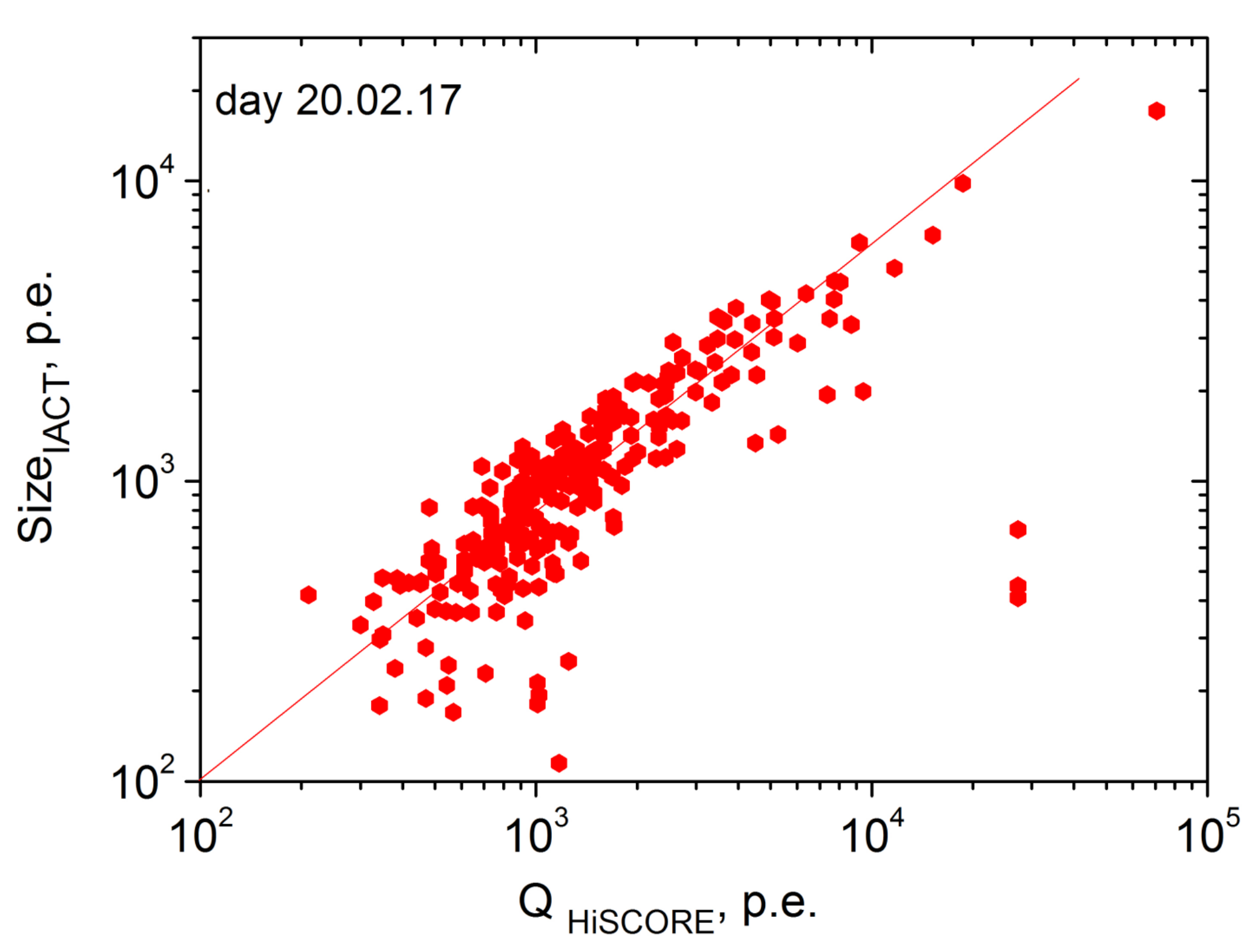
Before analyzing TAIGA-IACT images, all values of the signal amplitude in PMTs of the camera were transformed from ADC codes to photoelectrons, taking into account the difference between quantum efficiency of various PMTs as well as the difference between their sensitivity. After that the image cleaning procedure was performed to remove the night sky background light from images.

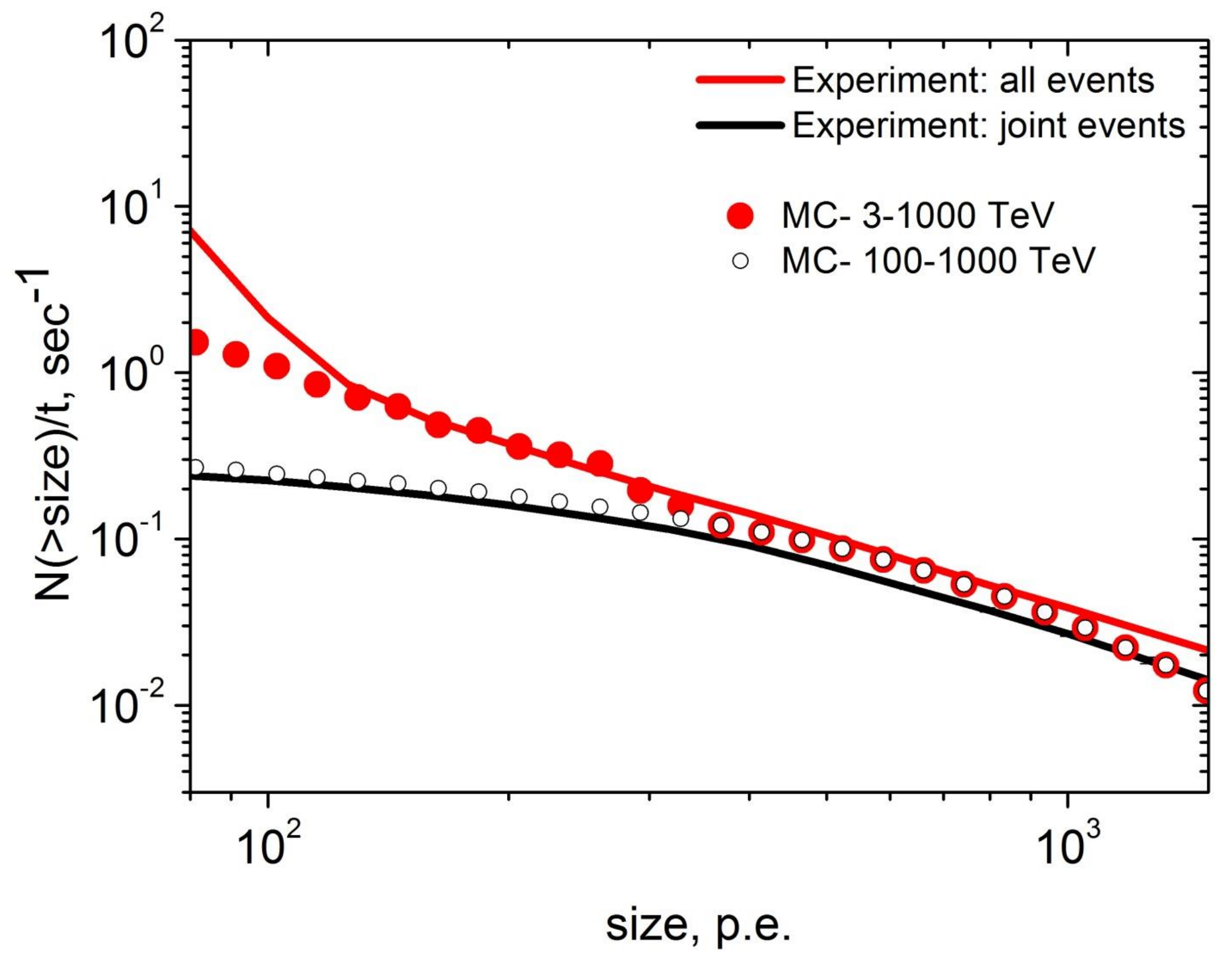
The figure presents an example of the joint event from the TAIGA prototype. For these events the EAS core position is determined by the timing array TAIGA-HiSCORE and projected onto the camera plane. The image major axis (which is an 'IACT prediction' of the EAS core direction; black line) is in good agreement with the direction to the HiSCORE-predicted core position (red line). Therefore, first IACT data indicated good agreement with the timing detectors data, which means a successful start of the first stage of the combined approach to γ-ray EAS detection (IACT + timing array).



An important characteristic of any IACT image is the so called 'image size', that is a total sum of all photoelectrons in the image. It's similar to the number of photoelectrons Q measured by the timing array TAIGA-HiSCORE. The comparison of the IACT image size with the prediction of this value obtained in TAIGA-HiSCORE is presented in the left figure. The prediction was taken as a result of the fit of lateral distribution function measured by HiSCORE. The dependence of the measured value on its predicted value is linear with some fluctuation around the theoretical line. This result both confirms the correct functioning of the IACT and demonstrates the possibility of using the IACT as an additional hit detector in the TAIGA-HiSCORE installation.

In the right figure the spectra of image size are presented for comparison of experiment and simulation. For illustration we show two Monte Carlo predictions: 3–1000 TeV and 100–1000 TeV. The figure demonstrates good agreement between the joint events and simulated ones with energies greater than 100 TeV, which is the joint event threshold (the corresponding threshold in photoelectrons is 300–400 p.e). The region 120–300 p.e. corresponds to the showers with energies E<100 TeV. The spectrum of all events (red curve) in the region to the left from 100–150 p.e. represents the readout of the night sky background events, which occasionally pass the trigger in a single PMT cluster. The energy threshold of a single IACT prototype is expected as 2–3 TeV.

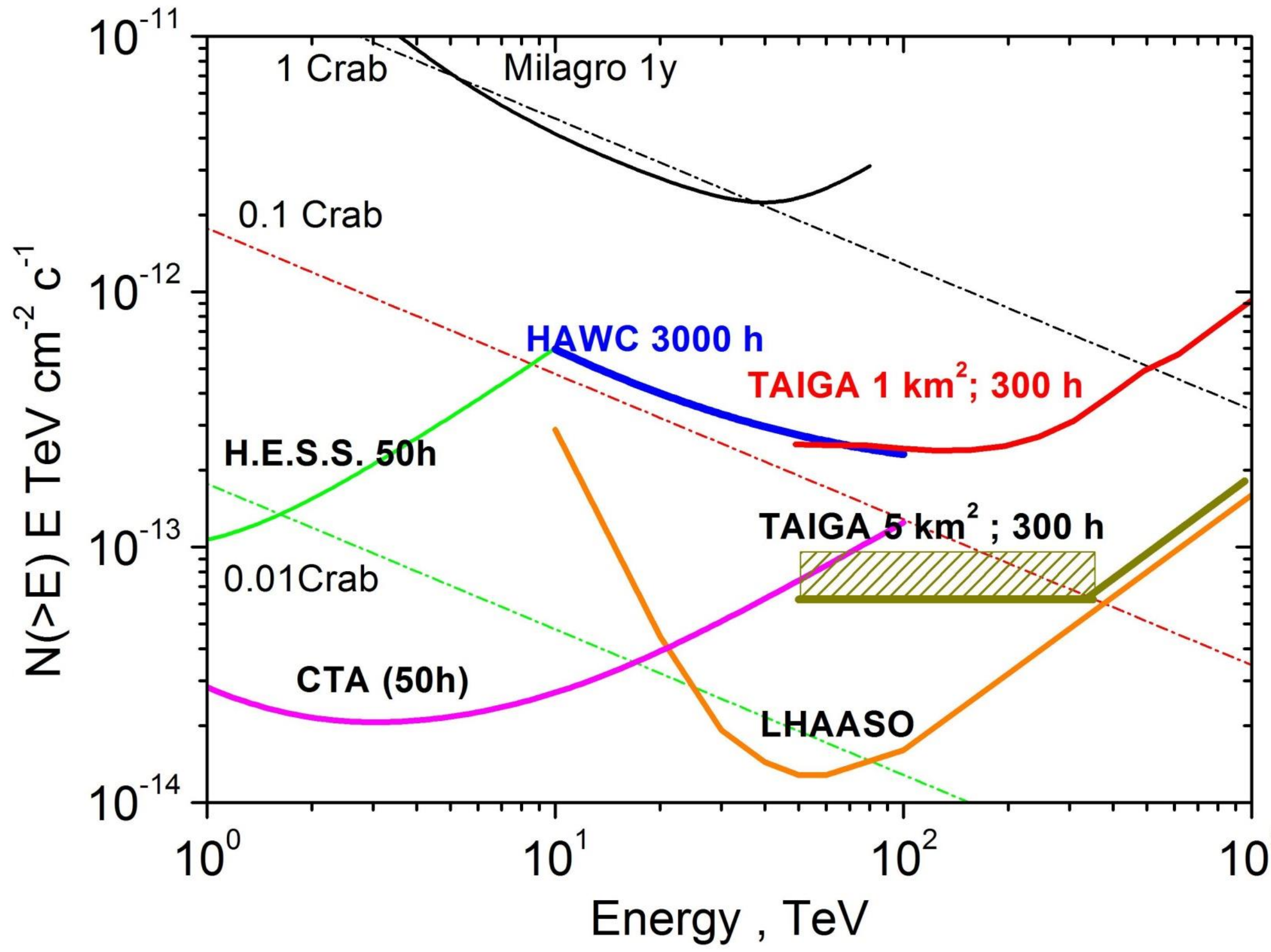




TAIGA advantages

TAIGA assumes relatively inexpensive approach to ground-based gamma-ray astronomy – a combined technique of using monoscopic IACTs simultaneously with timing detectors. The first IACT of TAIGA has already taken first data, two additional IACTs will be developed and put in operation in 2018–2019 for covering a total area of 1 km^2.

The TAIGA expectation of sensitivity to local sources is compared with various ground-based experiments in the figure.



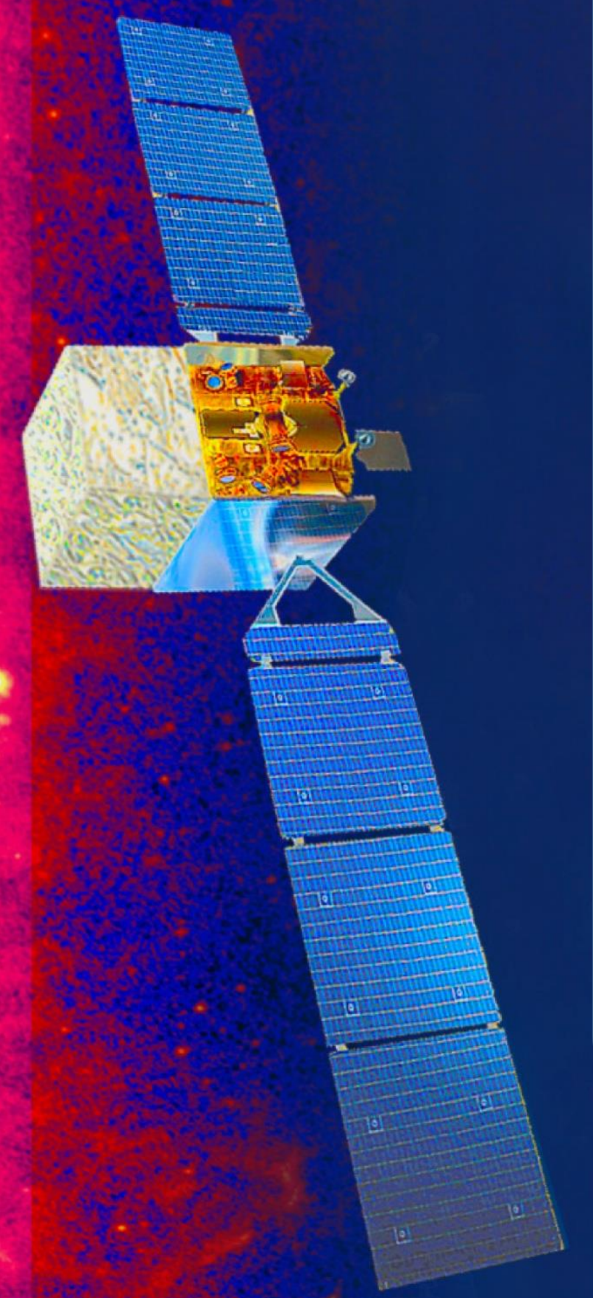
Name	RA degrees	Decl	Flux at 1 TeV, $10^{-12} cm^{-2} s^{-1} TeV^{-1}$ slope Γ	Flux at 35 TeV, $10^{-17} cm^{-2} s^{-1} TeV^{-1}$ (from Milagro)	Time of observation per one year (x 0.5- weater factor)
Tycho SNR (J0025+641)	6.359	64.13	0.17 ±0.05 Γ=1.95 ±0.5		**236h**
Crab	83.6329	22.0145	32.6 ±.9.0 Γ=2.6 ±0.3	162.6 ±9.4	**110h**
SNR IC443 (**MAGIC J0616+225**)	94.1792	22.5300	0.58 ±0.12 Γ=3.1 ±0.30	28.8 ±9.5	**112h**
Geminga MGRO C3 PSR	98.50	17.76		37.7 ±10.7	**102h**
M82 (Starburst Galaxy)	148.7	69.7	0.25 ±0.12 Γ=2.5 ±0.6±0.2		**325h**
Mkn 421 (BL, z=0.031 Variable)	166.114	38.2088	50-200 Γ=2.0-2.6		**140h**
SNR 106.6+2.7 (J2229.0+6114)	337.26	61.34	1.42 ±0.33 ±0.41 Γ=2.29 ±0.33 ±0.30	70.9 ±10.8	**167h**
Cas A (SNR)	350.853	58.8154	1.26 ±0.18 Γ=2.61 ±0.24±0.2		**177h**
CTA_1(SNR,PWN)	1.5	72.8	1.3 Γ=2.3		**266 h**

Another advantage is a geographical location of TAIGA, which allows 500 h/year observing Tycho's SNR, unavailable for HAWC and LHAASO arrays.

The other possible candidates for TAIGA observation (with a 1 km^2 area) are listed in a table.

Selected references

- L. Kuzmichev et al. Tunka Advanced Instrument for cosmic rays and Gamma Astronomy (TAIGA): Status, results and perspectives // EPJ Web of Conf. 145 (2017) 01001.
- Budnev N.M. et al. TAIGA experiment: present status and perspectives // Journal of Instrumentation 12, № 08 (2017) 08018.
- Budnev N. et al. The TAIGA experiment: From cosmic-ray to gamma-ray astronomy inthe Tunka valley // Nucl. Instr. Meth. Phys. Res., Section A 845 (2017) 330.
- Monkhoev R.D. et al. The Tunka-Grande experiment // Journal of Instrumentation 12, № 6 (2017) 06019.
- Gress O. et al. The wide-aperture gamma-ray telescope TAIGA-HiSCORE in the Tunka Valley: Design, composition and commissioning // Nucl. Instr. Meth. Phys. Res., Section A 845 (2017) 367.
- Apel W.D. et al. A comparison of the cosmic-ray energy scales of Tunka-133 and KASCADE-Grande via their radio extensions Tunka-Rex and LOPES // Physics Letters, Section B 763 (2016) 179.
- M. Tluczykont et al. The HiSCORE concept for gamma-ray and cosmic ray physics beyond 10 TeV // Astropart. Phys. 56 (2014) 42.
- Prosin V.V. et al. Tunka-133: Results of 3 year operation // Nucl. Instr. Meth. Phys. Res., Section A 756 (2014) 94.
- Budnev N. et al. Tunka-25 Air Shower Cherenkov array: The main results // Astropart. Phys. 50–52 (2013) 18.



TAIGA