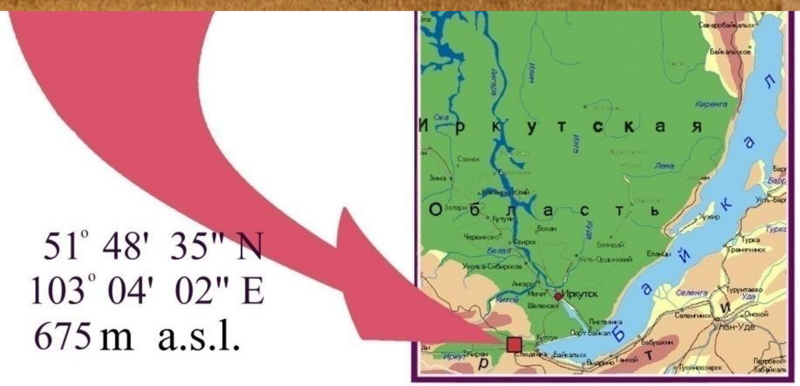
The TAIGA - an hybrid detector complex in Tunka valley for astroparticle physics, cosmic ray physics and gamma-ray astronomy.



N. Budnev,

L. Kuzmichev

For TAIGA collaboration

TAIGA - Collaboration

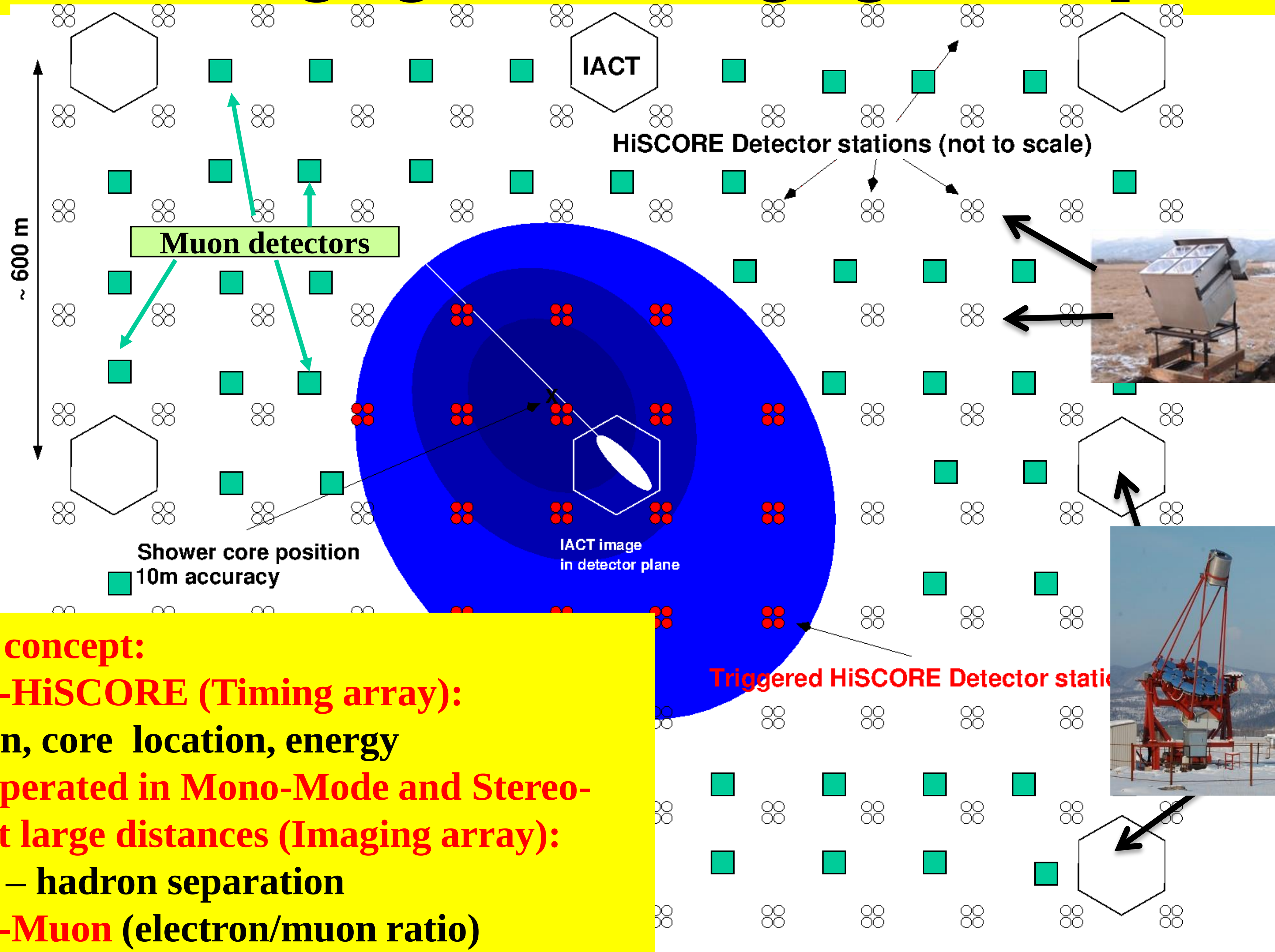
- Irkutsk State University (ISU), Irkutsk, Russia
- Scobeltsyn Institute of Nuclear Physics of Moscow State University (SINP MSU), Moscow, Russia
- Institute for Nuclear Research of RAS (INR), Moscow, Russia
- Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation of RAS (IZMIRAN), Troitsk, Russia
- Joint Institute for Nuclear Research (JINR), Dubna, Russia
- National Research Nuclear University (MEPhI), Moscow, Russia
- Budker Institute of Nuclear Physics SB RAS (BINP), Novosibirsk, Russia
- Novosibirsk State University (NSU), Novosibirsk, Russia
- Altay State University (ASU), Barnaul, Russia
- Fisica Generale Universita di Torino and INFN, Torino, Italy

The TAIGA - a hybrid array for very High energy gamma-ray astronomy, cosmic ray physics and astroparticle physics in the Tunka valley

The main idea: **A cost effective way to construct a large area installation for high energy gamma-astronomy is joint operation of wide-field-of-view timing Cherenkov detectors** ***with a few relatively cheap, small-sized imaging Air Cherenkov Telescopes.***

The first stage of TAIGA-1 - 1 km^2 area array with 120 wide-angle timing Cherenkov detectors and 3 IACTs Is in operation since 2022y.

TAIGA: Imaging + non-imaging techniques



Hybrid concept:

TAIGA-HiSCORE (Timing array):

direction, core location, energy

IACT operated in Mono-Mode and Stereo-Mode at large distances (Imaging array):

gamma – hadron separation

TAIGA-Muon **(electron/muon ratio)**

TAIGA Scientific Program

1. Study of energy spectrum of gamma-rays from galactic sources: Crab Nebula. J2227+610 (G106.3+2.7), Dragonfly Nebula (J2019+367) , J2031+4157 (Cygnus Cocoon), Tycho and search for new sources.

2. Long-term monitoring and study of the bright blazars energy spectrum: 1 ES 0229+200, 1ES 1959+650, Mrk 501, Mrk 421, Arp 220, M82

3. Search for an excess of diffuse gamma rays with energies above 100 TeV

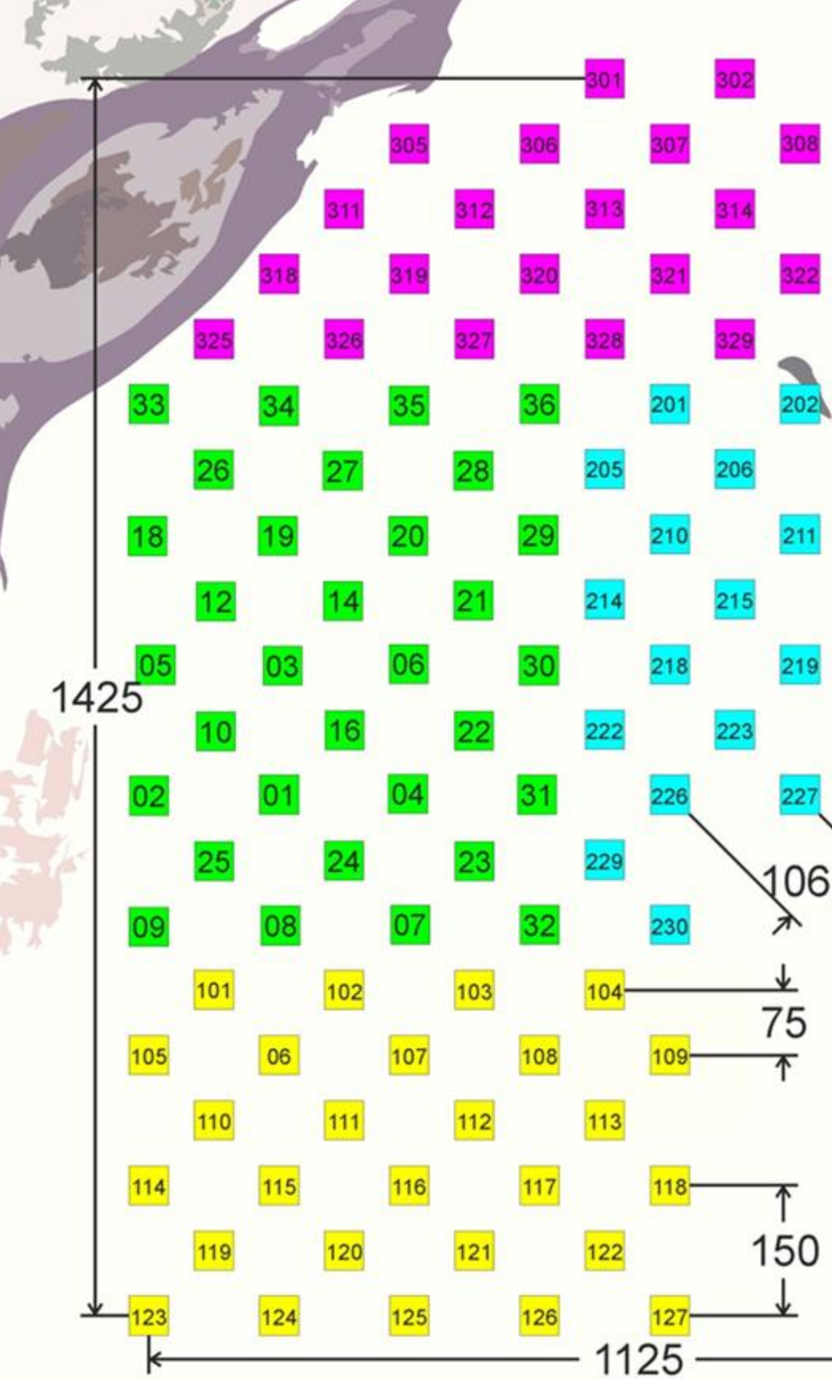
4. Search for gamma quanta from close GRBs and associated with IceCube and Baikal-GVD neutrinos.

4. Search for Astrophysical Nanosecond Optical Transients with TAIGA-HiSCORE Array.

5. Study of the CR energy spectrum and mass composition in energy range 100 TeV- 1000 PeV.

6. Fundamental physics (photon-axion oscillation, indications of Lorentz invariance violation etc).

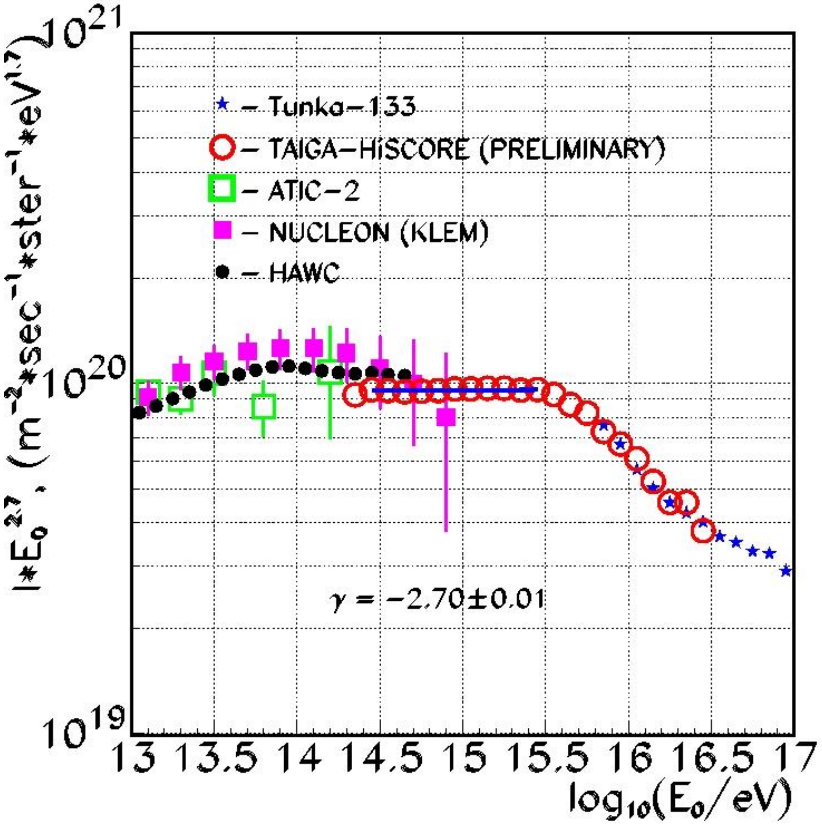
TAIGA-HiSCORE



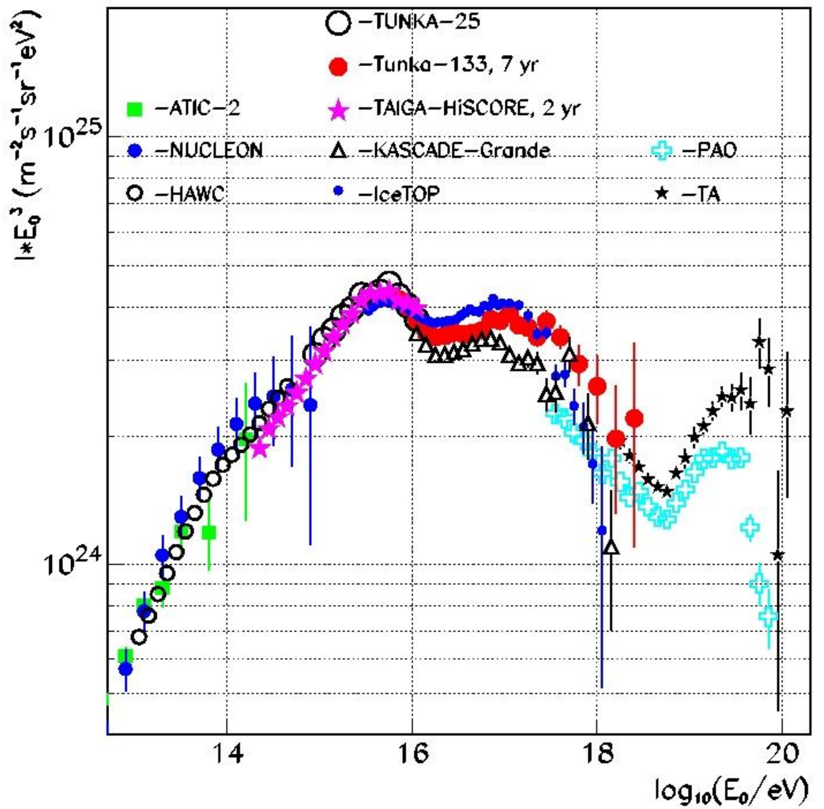
120 optical station on 1,1 km² aria

Advantage of a wide – angle tuming Cherenkov array:

- Good accuracy positioning of EAS core (5 -10 m)
- Good energy resolution (10 - 15%)
- Good angular resolution (~ 0.15 degree)
- Good accuracy of Xmax measurement (~ 20 -25 g/cm2).
- Low cost (~ 10^6 Euro/ km^2)



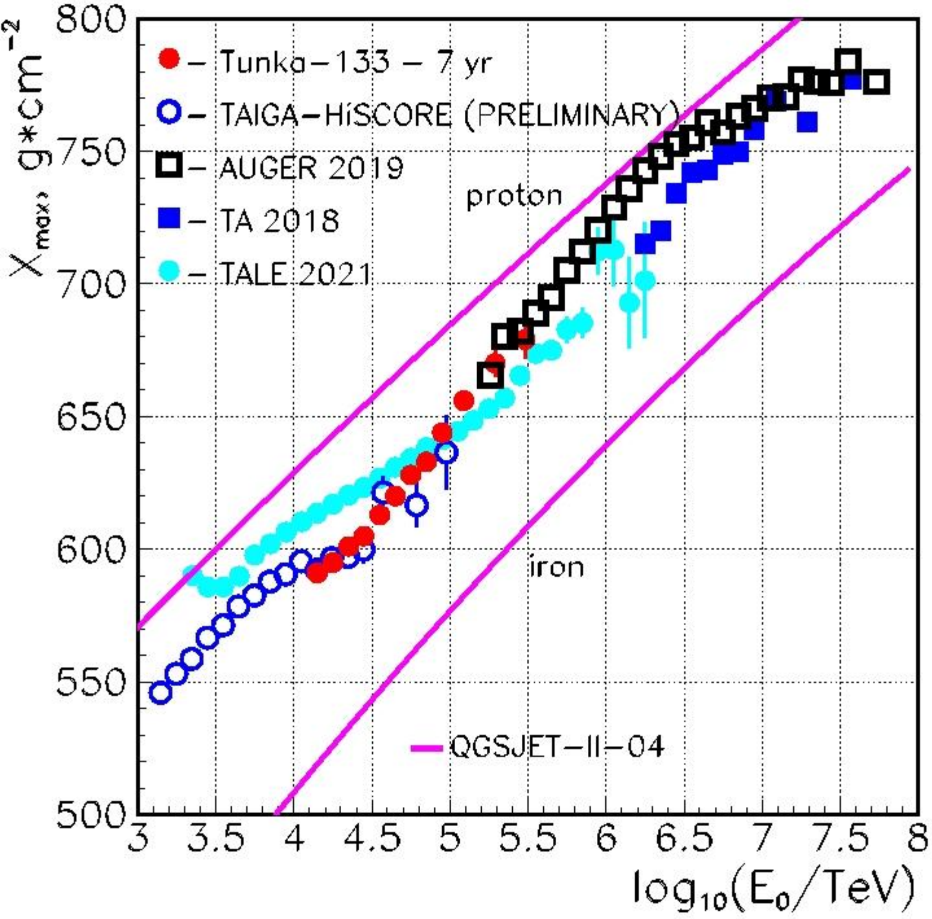
TAIGA-HiSCORE energy spectrum

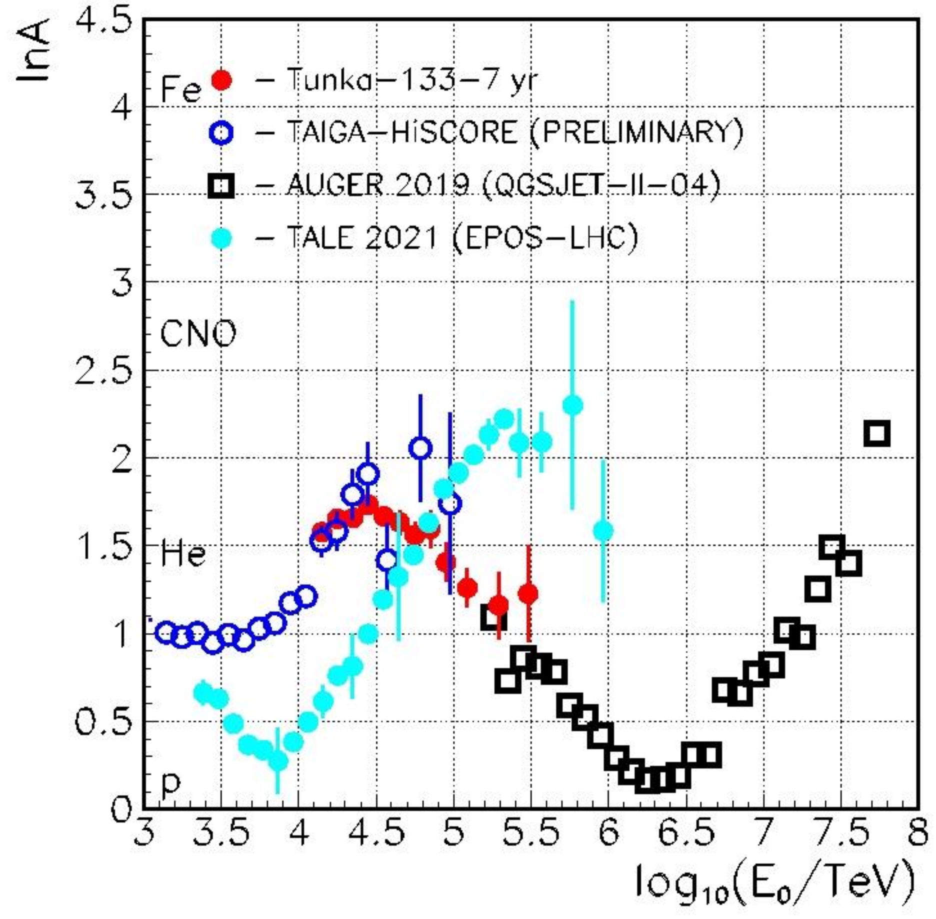


Comparison of the Tunka-25 &Tunka-133 & TAIGA-HiSCORE energy spectra with other experimental results

Mean Depth of EAS maximum X_{max} ($g \cdot cm^{-2}$)

Mean logarithm of primary mass.





Search for astrophysical nanosecond optical transients with TAIGA-HiSCORE array

Expected signatures:

1. Small amplitude spreading among the triggered optical stations in an event

2. Good fit of optical stations response times by an exactly plane optical front

3. Uniform distribution of positions of flashed optical stations upon the surface of the TAIGA-HiSCORE array (no spot-like distribution like in EAS)

The first results

Limits for the optical transient flux

The observation time in the winter season 2018-2019 (½ of the TAIGA-HiSCORE array) was 475 hours for a solid angle of 0.6 ster, which gives an exposure of 288 sr·hour.

No optical transients were found =>

An approximate upper limit on the rate of events is:
for events with a flux density of photons greater than 10^{-4} erg/s/cm^2 and with a duration greater than ~5 ns,
the flux is less than ~2×10^{-3} events/sr/hour (preliminary)

It is planned to conduct continuous data analysis for the entire installation

The TAIGA – IACT

The TAIGA - IACT

First 2017y, second 2019y, third 2022y

situated at the vertices of a triangle

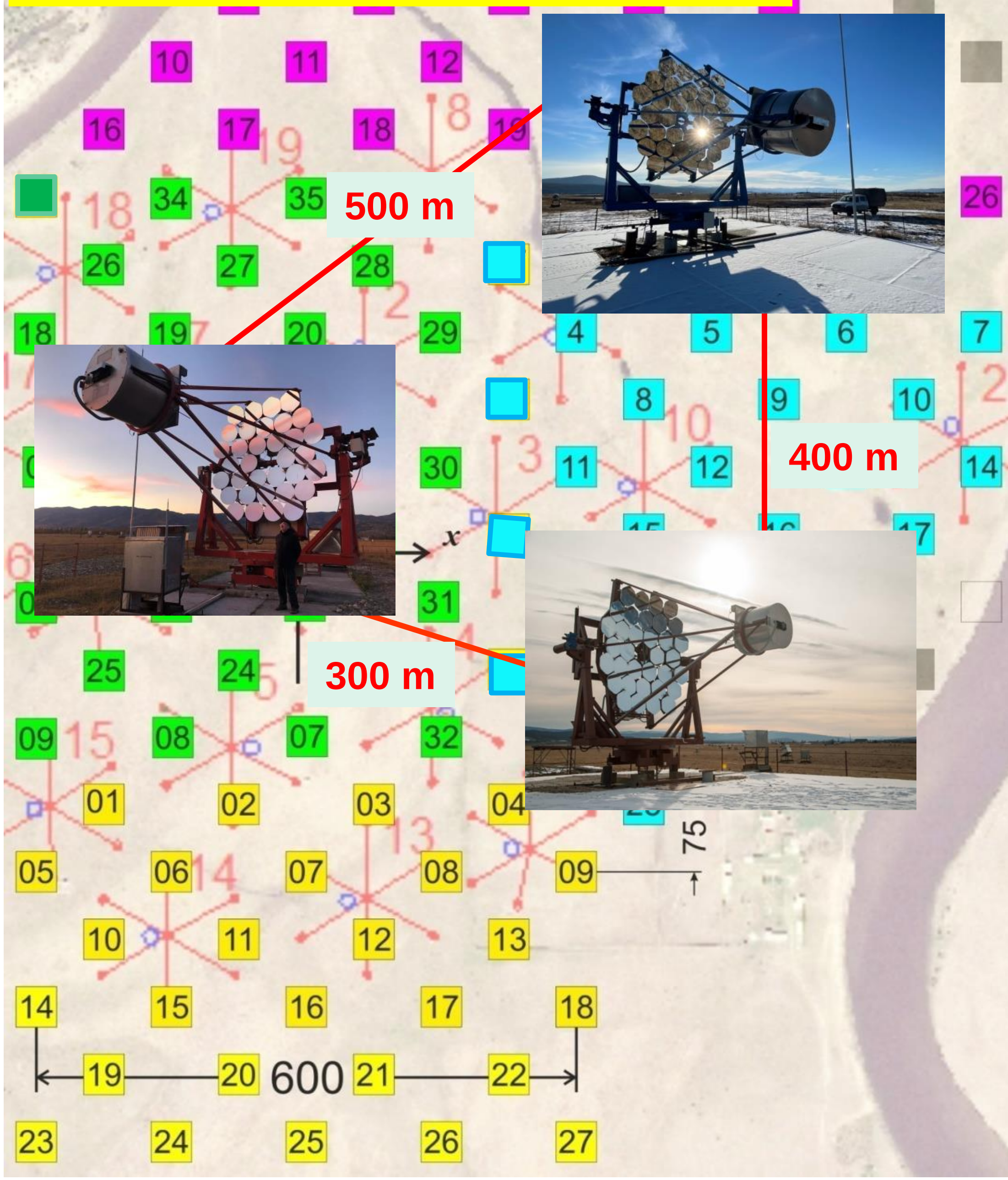
with sides:

300 m, 400 m and 500 m about

- **34-segment reflectors (Davis-Cotton)**
- **Diameter 4.3 m, area ~10 m^2**
- **Focal length 4.75 m**
- **Threshold energy ~ 2 - 3 TeV**

.

TAIGA-1, 2022year



Four modes for detecting gamma rays in the TAIGA experiment

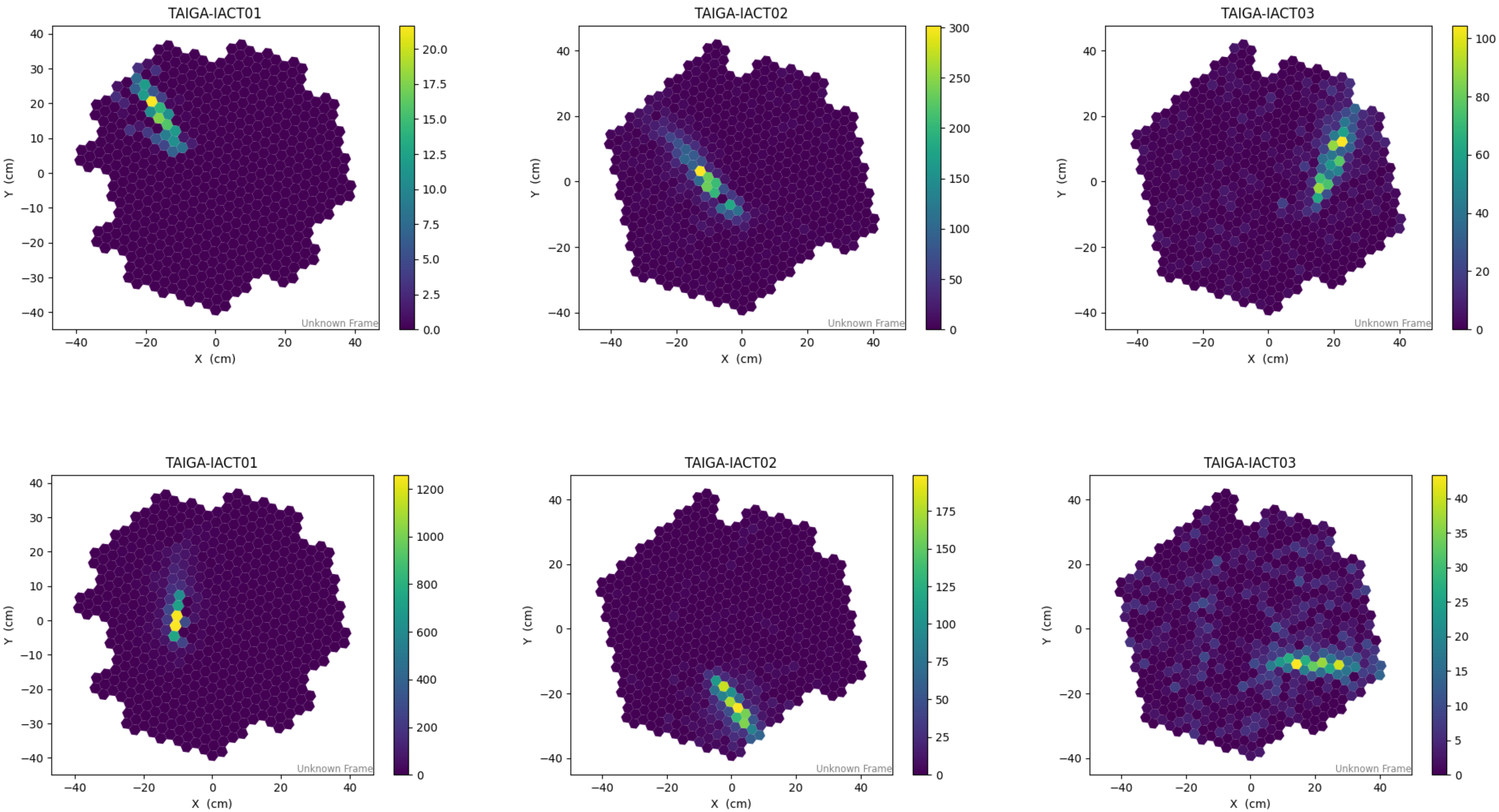
1. Standalone mode of IACTs operation (E> 2-3 TeV)

2. Stereoscopic mode for large distances between the IACTs for E > 8 TeV

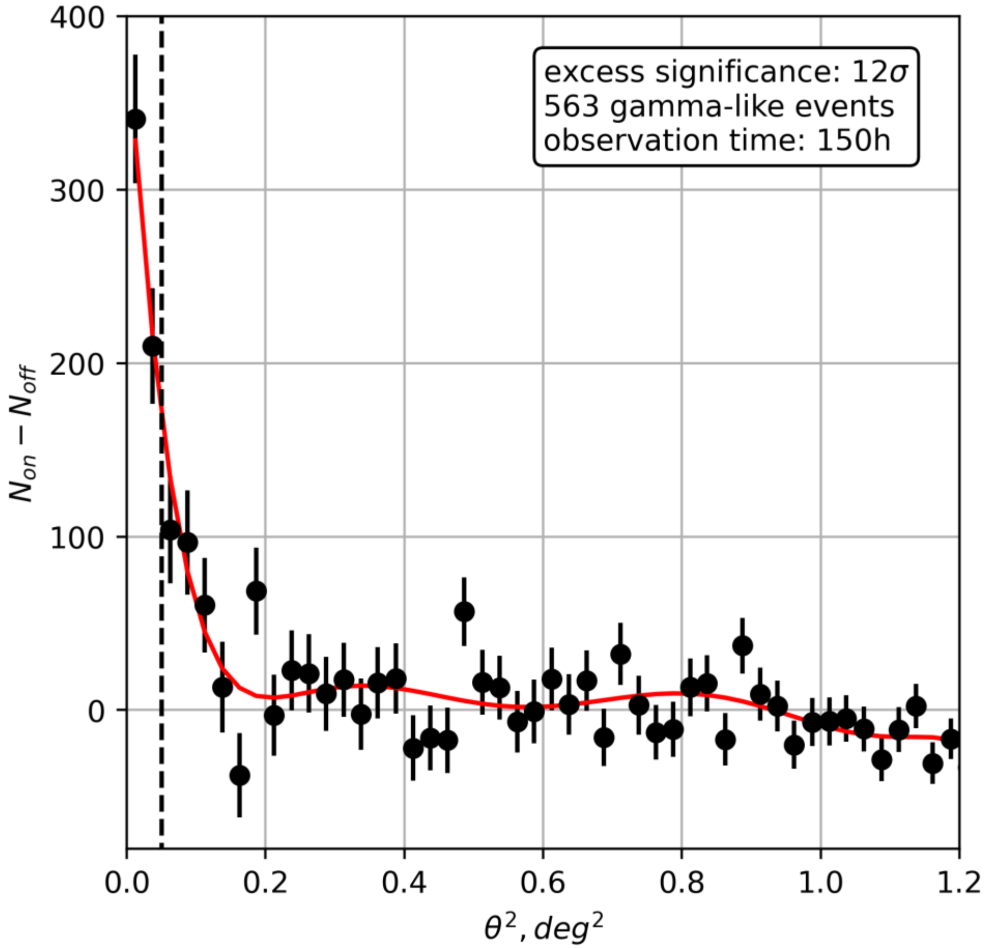
3. Hybrid mode - joint operation of the TAIGA-HiSCORE and the IACTs
   for E > 40 TeV.

4. TAIGA- HiSCORE > 100 TeV (probably an additional hadron suppression is required)

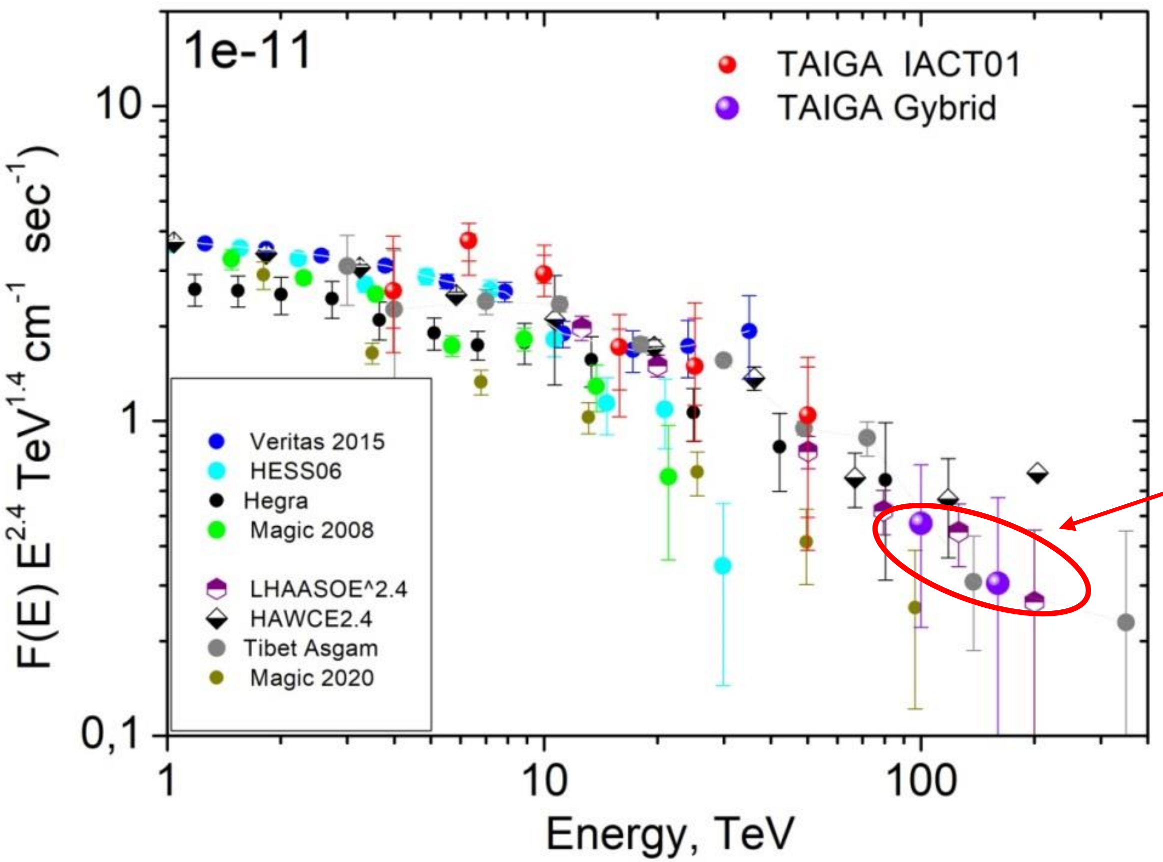
EAS detection by three IACT at a distance of 300 m – 400 m – 500 m in stereoscopic mode for high energies



Background subtracted Θ^2-distributions for 150 hours Crab Nebula observation



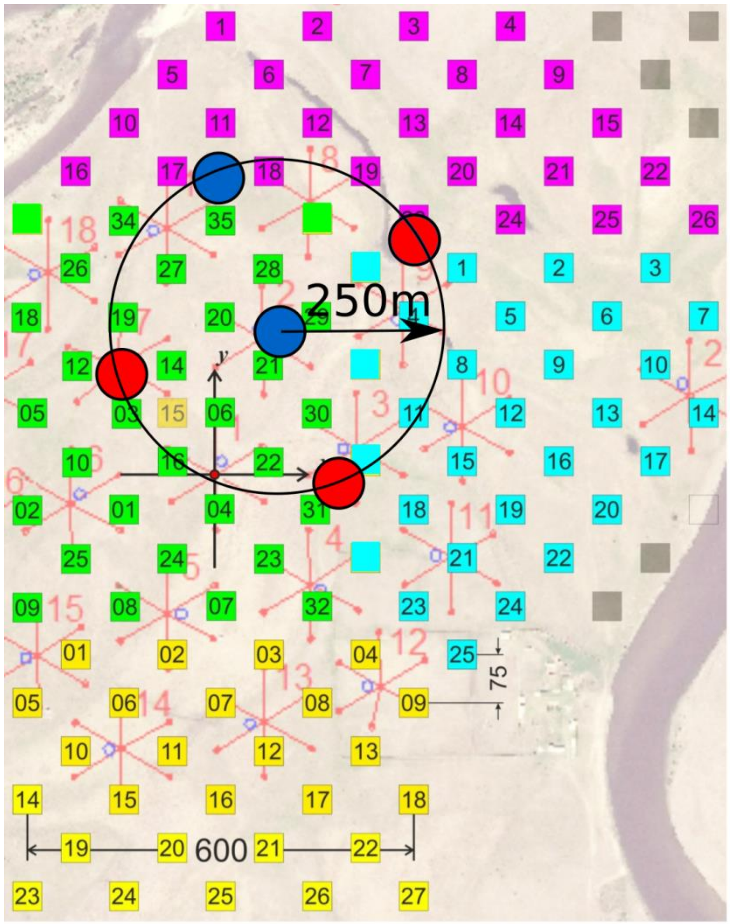
The energy spectrum of gamma quanta from the Crab Nebula (150 hours)



Hybrid events
6 events
$0.25\ km^2$

TAIGA -1 : >100 TeV 300 h (2-3 seasons) 40-60 gamma,

TAIGA-1, 2023



IACT in operation

planned IACT

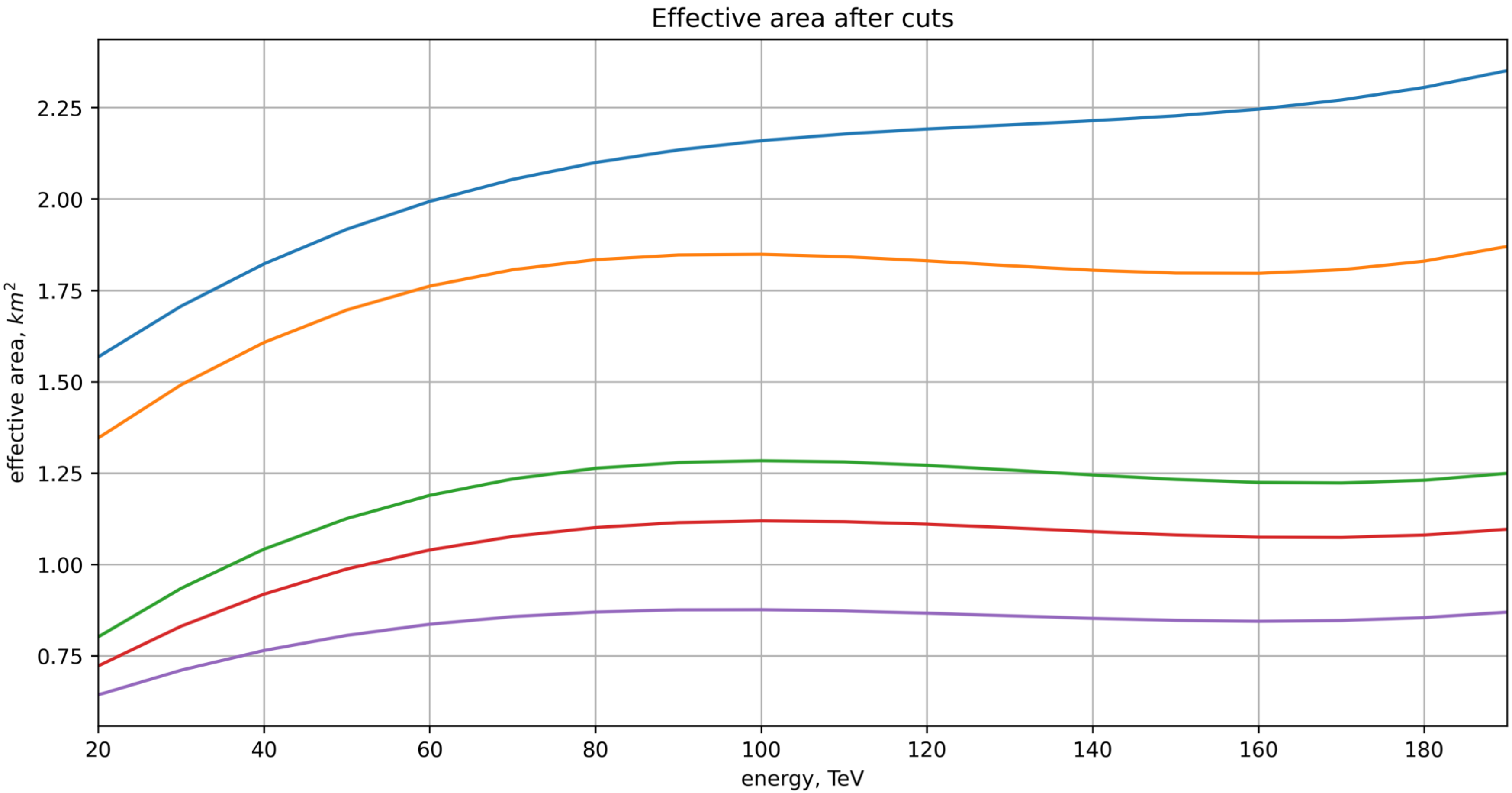
HiSCORE cluster#1

HiSCORE cluster#2

HiSCORE cluster#3

HiSCORE cluster#4

Effective area for the five IACT of the TAIGA observatory



Standalone mode of IACTs operation (E> 1.5 TeV)

Standalone mode of IACTs operation with cuts XYc < 3.5 deg., size > 120 phe

Stereoscopic mode, 2 and more IACT

Stereoscopic mode, 2 and more IACT, source location <0.36 deg

Stereoscopic mode, 2 and more IACT, normalized width < 0.6

A future 10 square kilometer scale hybrid array for astroparticle physics, gamma-astronomy and cosmic ray physics

Energy range
50 TeV – 1 PeV.
300- 400 gamma from Crabe Nebule with Energy > 100 TeV
For 300 hours

+

+

TAIGA-HiSCORE - array. A net of 1000 non imaging wide-angle detectors distributed on area 10 km^2 *with* spacing 100 m about
An EAS core position, direction and energy reconstruction.

TAIGA-IACT - array
of 5-10 IACT with mirrors – 4.3 m diameter.
Charged particles rejection using imaging technique.

The net (50-100) of wide angle (30°) Small Imaging Telescope (SIT), 1/5 diameter mirror, SiPM based camera

Summary and outlook

TAIGA aims to develop a new hybrid technology for studying gamma rays with an energy of >30 TeV

2022 year 1 km^2 TAIGA-1 setup:

- **120 wide – angle Cherenkov detectors of TAIGA - HiSCORE "non-imaging" timing array**
- **3 Imaging Atmospheric Cherenkov Telescopes of TAIGA-IACT "imaging" array**
- **150 m^2 muon detectors of TAIGA-Muon and Tunka-Grande arrays.**

A point source sensitivity: 2.5 10^{-13} TeV/cm^2 s (300 hours, 30–200 TeV)

- **CR energy spectrum 100 TeV – 1 EeV**
- **Detection of gamma-rays from Crab Nebule, Mrk-421 etc in agreement with expectation.**
- **Near Future plan: 2 new IACT, new particle detectors, Small Image Telescopes (SIT) with a SiPM-based camera with a FoV up to 60°**

Next plan: 10 square kilometers scale TAIGA + new technologies

- **array with about 1000 Cherenkov detectors of TAIGA - HiSCORE "non-imaging" timing array**
- **5 – 10 Imaging Atmospheric Cherenkov Telescopes of TAIGA-IACT array**
- **3000 m^2 muon detectors of TAIGA-Muon array.**
- **The net (50-100) of wide angle (30°) Small Imaging Telescope (SIT), 1/5 diameter mirror,**
- **SiPM based camera**
- **A point source sensitivity: 2.5 10^{-14} TeV/cm^2 s (300 hours, 30–200 TeV)**