TAIGA Experiment: From Cosmic Ray to Gamma-Ray Astronomy in the Tunka Valley

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Tunka Advanced Instrument for cosmic rays and Gamma Astronomy

TAIGA - complex instrument for studying astrophysical processes by means of detecting various components of air-showers in the very-high energy range.

Goals:

* search for galactic sources of gamma rays with energies higher than 30 TeV;
* gamma-radiation fluxes from the Crab nebula and Tycho SNR;
* gamma rays from the most bright blazars;
* search for possible axion-photon transitions (candidates to DM particle);
* flux of ultra-high energy primary cosmic rays.

~ 80 scientists from 15 institutes (EU + Russia)

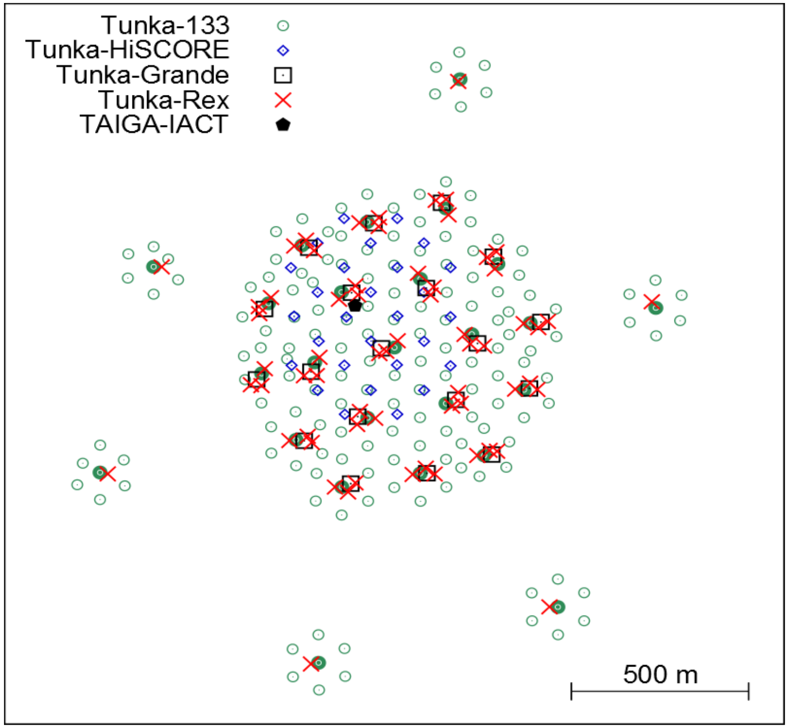
TAIGA:

Cosmic ray detectors (<EeV)

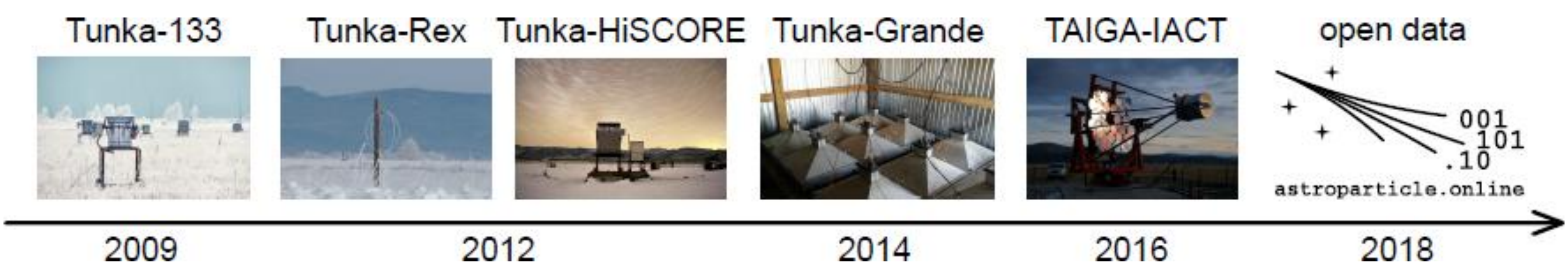
* Tunka-133 air-Cerenkov
* Tunka Radio Extension (Tunka-Rex)
* Tunka-Grande scintillators

Gamma ray detectors (>TeV)

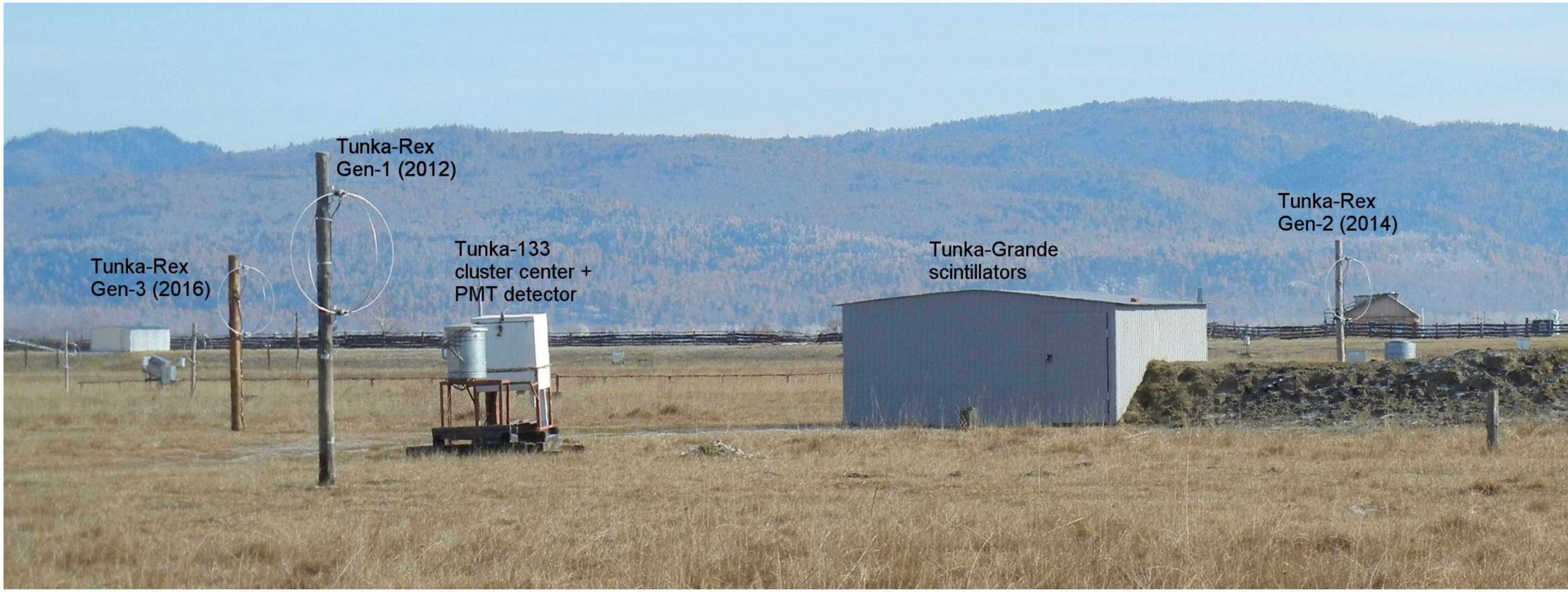
* TAIGA-HiSCORE
* TAIGA-IACT
* TAIGA-muon



approx. 50 km from Lake Baikal in the Tunka valley

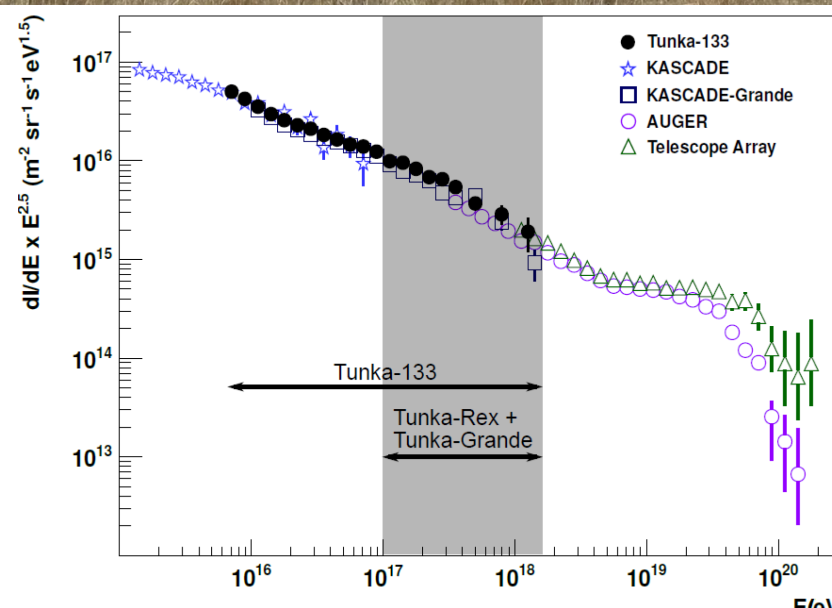


Cosmic ray studies up to several EeV



Science objectives

All-particle energy spectrum and mass composition in galaxy → extra-galaxy region



Tunka-133

Detector

* 3 km² Cherenkov array
* 25 clusters, 7 wide-angle optical detectors in each cluster
* Flash ADC: 200 MHz, 12 bit
* PMTs: EMI 9350 Ø 20 cm
* Short time of operation (moonless, cloudless nights)

Reconstruction resolution:

* arrival direction ~ 0.1-0.3°
* axis position ~ 5–10 m
* E_{pr} ~ 10%
* X_{max} ~ 25 g/cm²

Reconstruction concept

$E = A \cdot [N_{ph}(200m)]^g$

$g = 0.94 \pm 0.01$

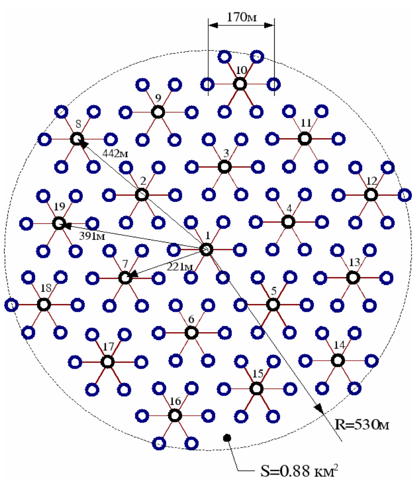
FWHM ~ ΔX g/cm² ,

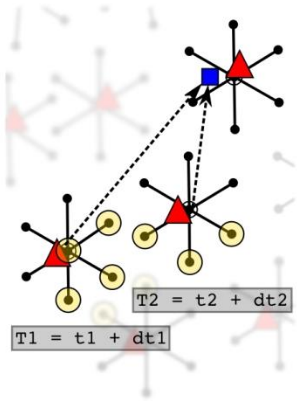
$\Delta X = X_0/\cos\theta - X_{max}$

X_{max} = C-D*lg τ (400)

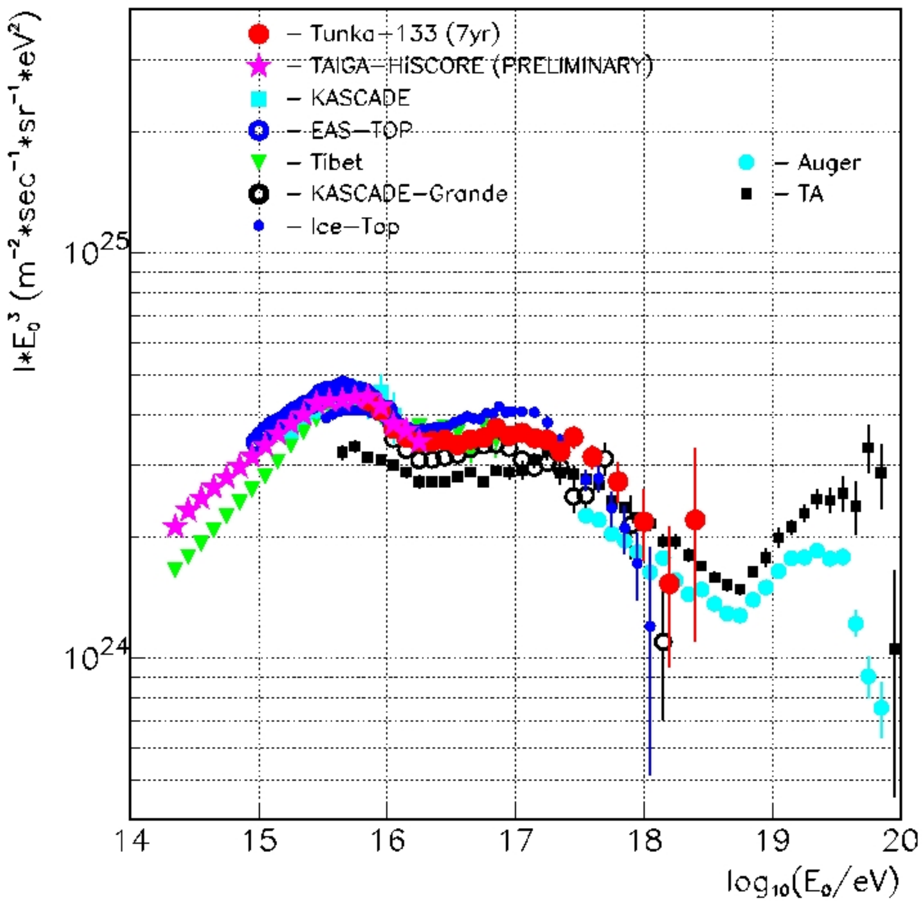
X_{max} = F(P),

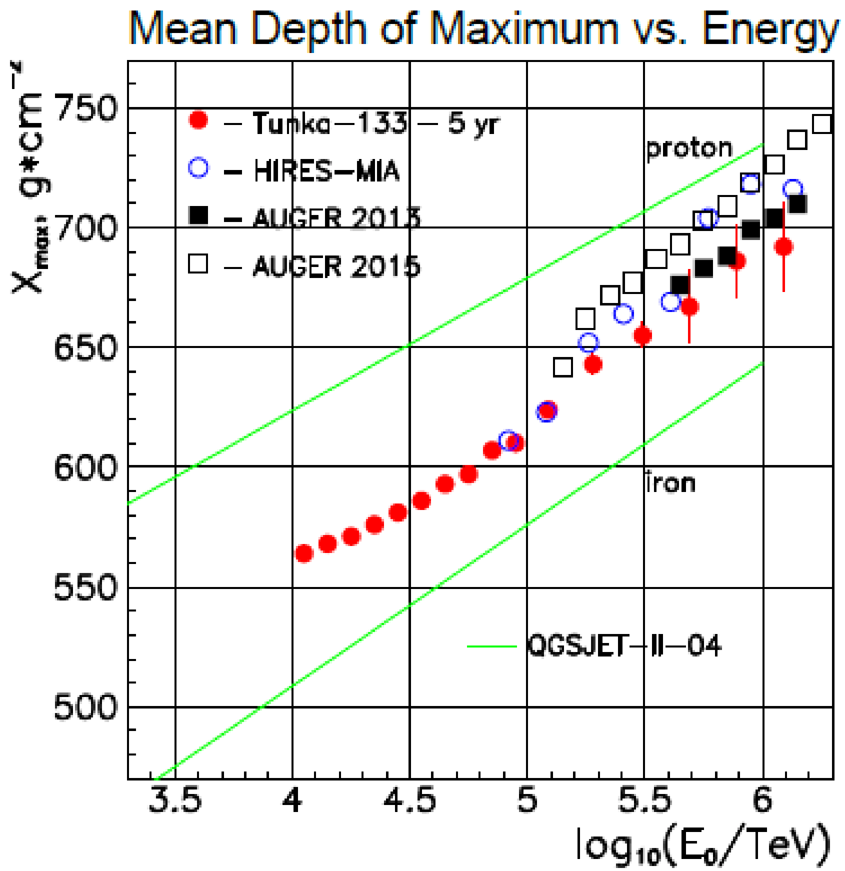
P - LDF slope





Comparison of energy spectra obtained at Tunka-133 with some other experiments





* < 10^{17} eV: consistent with KASCADE-Grande and Ice-TOP

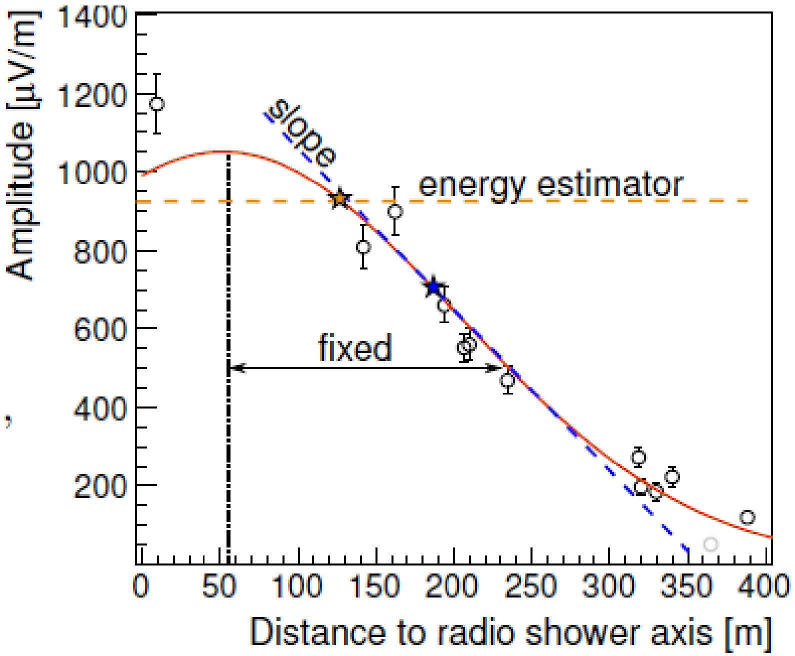
* >10^{17} eV: consistent with fluorescent light experiments: Auger and TA

Primary mass composition becomes heavier in the energy range 10^{16}–$3 \cdot 10^{16}$ eV and lighter again in the range 10^{17}–10^{18} eV.

Detector

* 63 antenna stations on 1 km^2 (200 / 20 m spacing between / inside clusters)
* Antenna type SALLA (Loop antenna with isotropic pattern)
* frequency band 30-80 MHz
* triggered by Tunka-133 and Tunka-Grande
* Threshold ~ 100 PeV

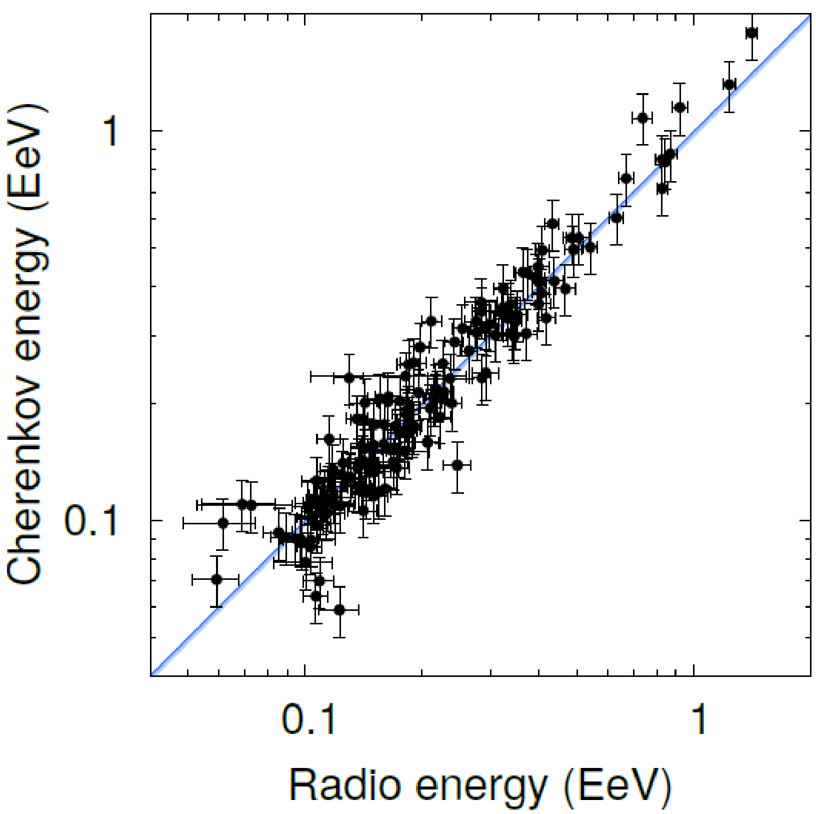
Reconstruction concept



Cross-check with Tunka-133 (2012-2014 seasons)

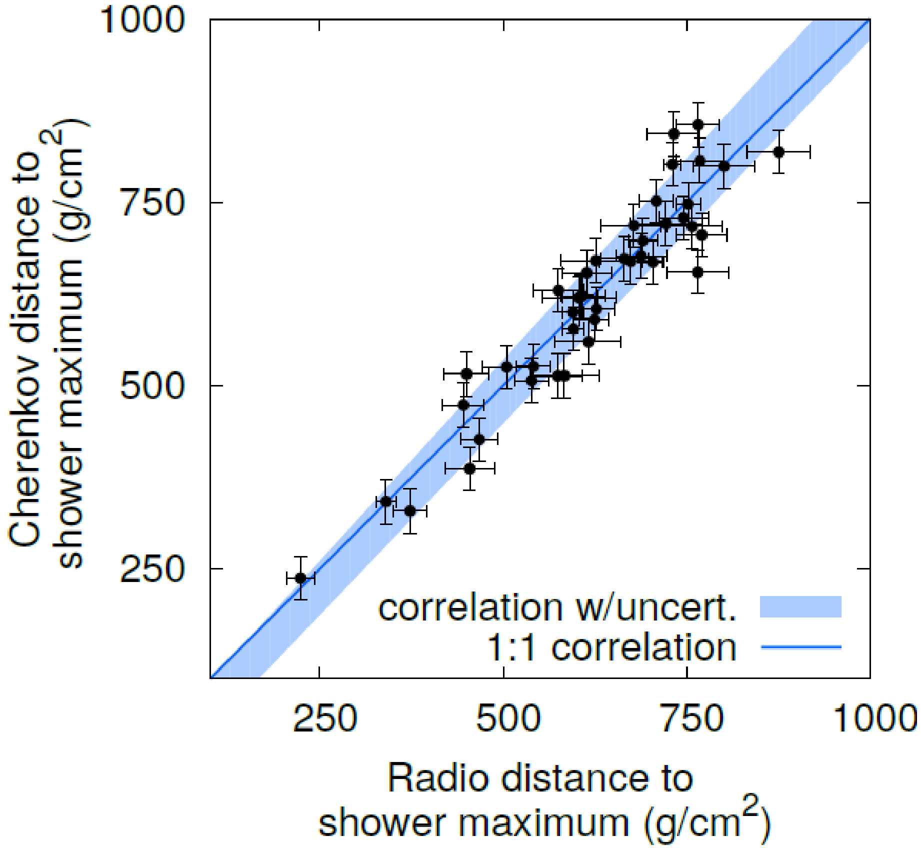
* blind cross-check Tunka133/Tunka-Rex
* experimental proof of X_{max} sensitivity

Energy



resolution: 15%

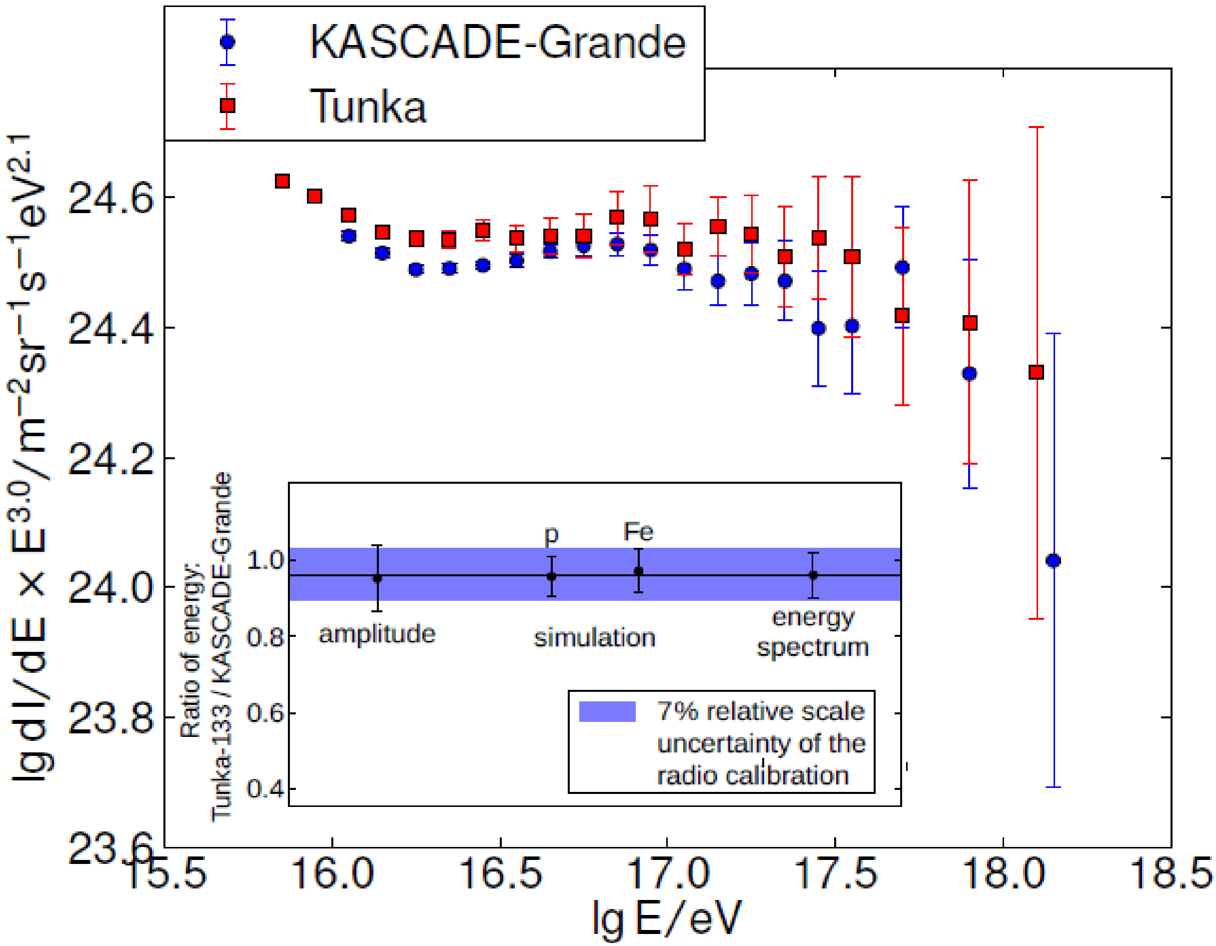
Shower maximum



resolution: 38 g/cm^2

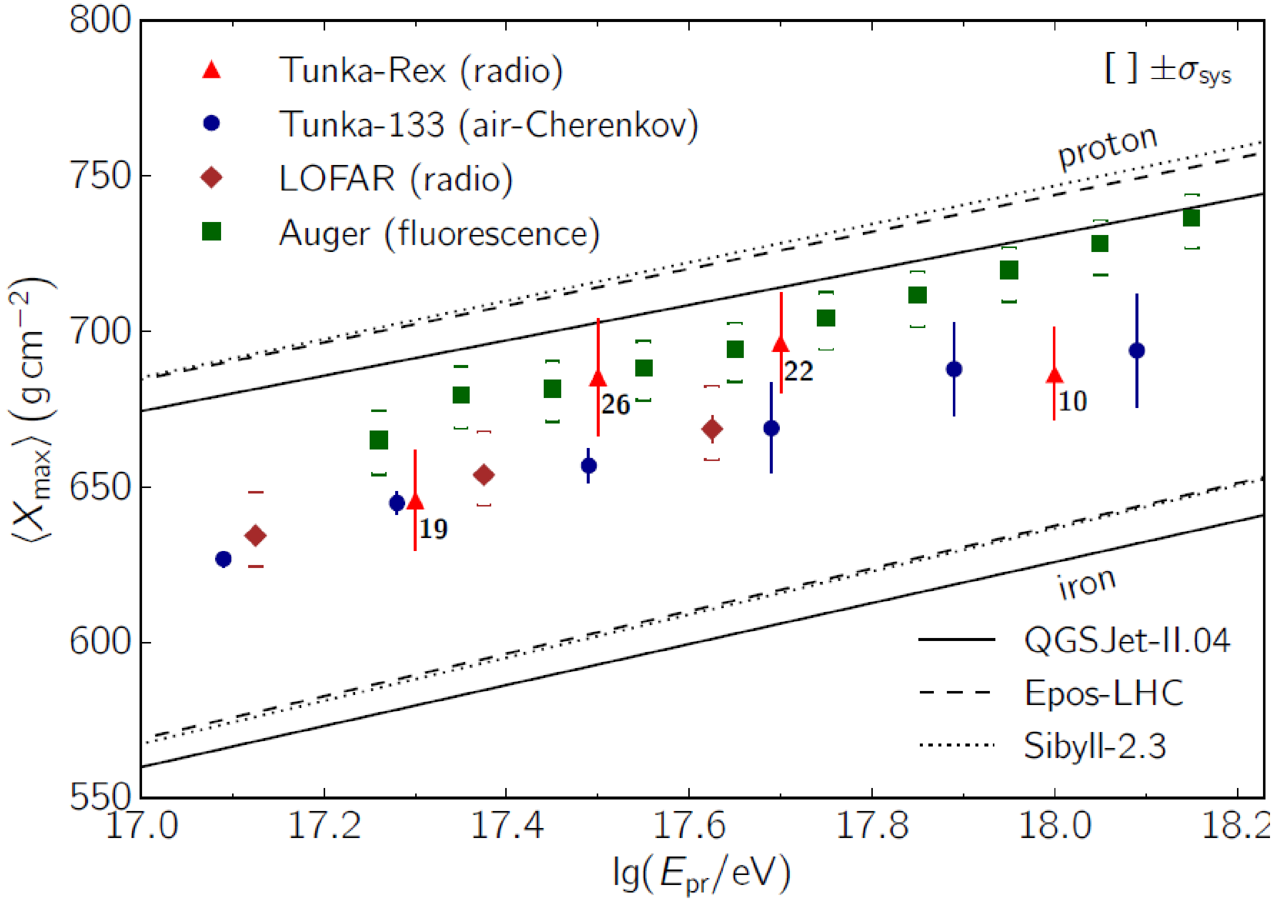
Comparison of energy scales of Tunka-133 and KASCADE-Grande

* Tunka-Rex calibrated by same reference source as LOPES
* Energy scales compared via CoREAS simulations using Tunka-133 and KASCADE-Grande energies as input
* Independent check via LOPES and Tunka-Rex has shown that energy scales of KASKADE-Grande and Tunka-133 are consistent within 10%



Average X_{max} as function of energy

* Tunka-Rex results are in agreement with other experiments.
* The good agreement between the three techniques shows the progress in the understanding of air-shower phenomena and systematics of experiments exploiting these techniques.



doi:10.1103/PhysRevD.97.122004

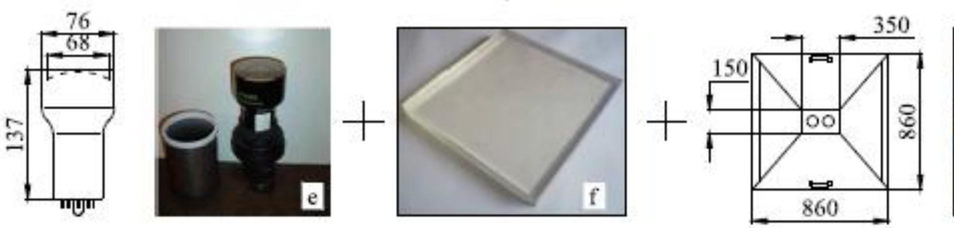
Detector:

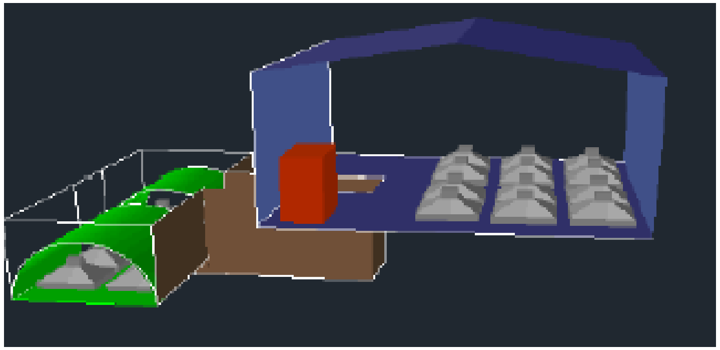
* 19 scintillator stations with spacing 200 m on 1km^2
* Each station consists of electron (8 m^2) and muon (5 m^2) detectors
* Independent trigger for station, synchronization via opric fibers
* Almost fully duty-cycle

→Mass composition from N_e/N_m

From simulation for energies > 100 PeV:

* N_e ~10% precision, N_m- 25%
* arrival direction ~ 1.4˚
* core position - 17 m
* E_{pr} - 20%

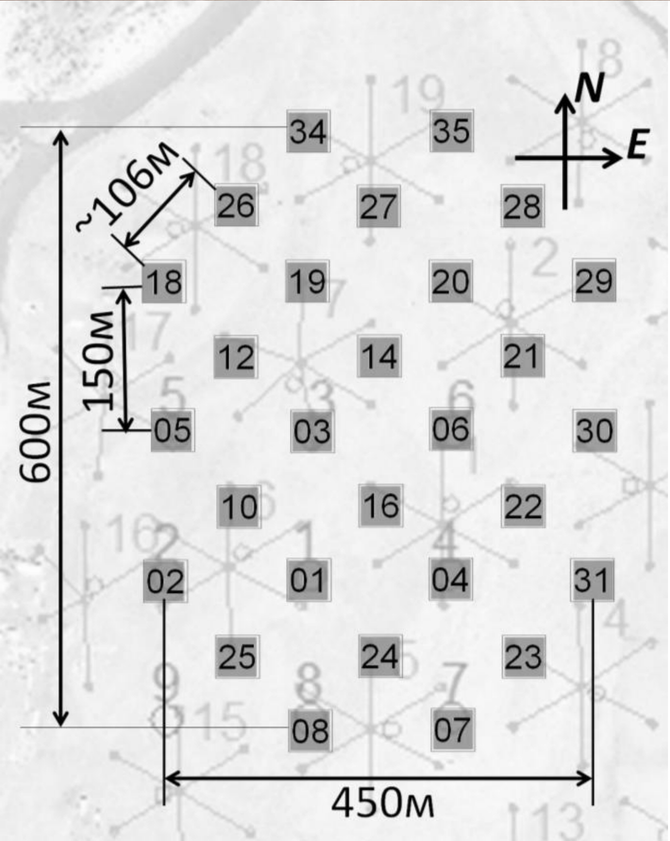




Ground-Based Gamma-Ray Astronomy from a Few TeV to Several PeV

Detector:

* High Sensitive Cosmic ORigin Explorer
* Non-imaging Cerenkov array like Tunka-133, but the threshold is 20 times lower
* will consist of 500 optical detectors with spacing 106 m on the area 5km^2 (now 43 detectors on area 0.5 km^2)
* Large FOV ~ 0.6 sr, angular resolution ~ 0.1°
* Good sensitivity to the EAS parameters



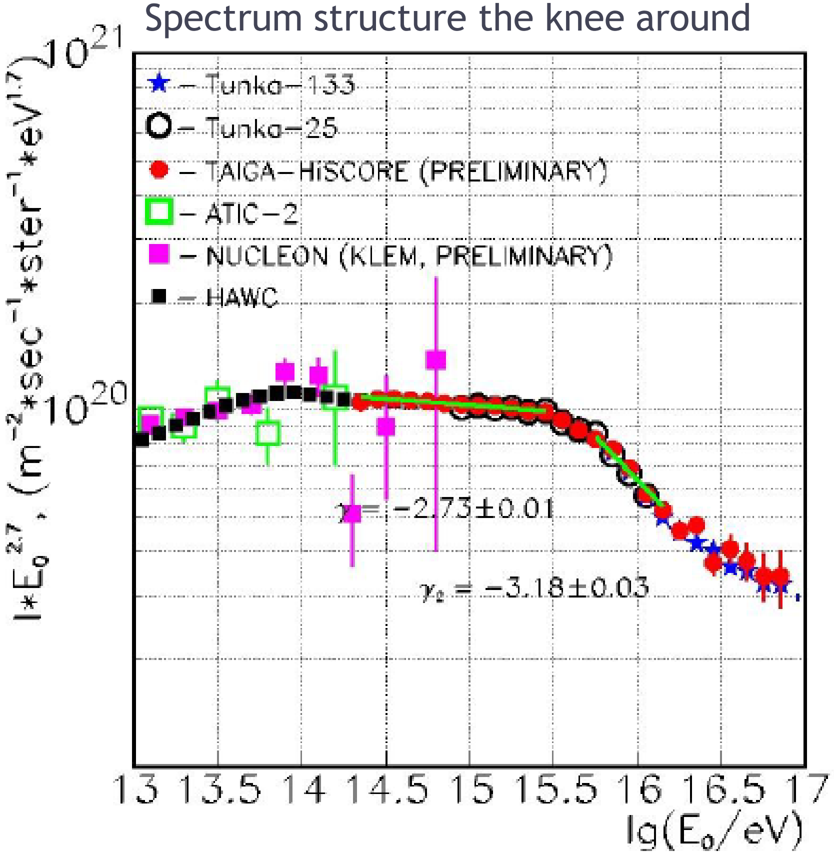
Reconstruction resolution:

* arrival direction ~ 0.1°
* axis position ~ 5–6 m
* E_{pr} ~ 10–15%
* X_{max} ~ 20–25 g/cm^2

First TAIGA-HiSCORE spectrum (data from Feb to Apr of 2017)

* Events with high multiplicity (mostly CR) are reconstructed with standard (similar to Tunka-133) method
* Events with low multiplicity (CR+ γ) are reconstructed with simplified method (core = center of gravity, etc.)
* TAIGA-HiSCORE provides information on the detailed shape of the spectrum at and before the knee
* HiSCORE is not able to make γ/h separation on event level

Spectrum structure the knee around



* Imaging air-Cherenkov telescopes
* will comprise 16 telescopes with spacing of 600-1000 m.
* Gamma/hadron separation
* Optical system: Davis-Cotton design reflector and photomultiplier-based camera
* First IACT in monoscopic mode is not able to resolve shower axis

Camera:

* 547 hexagonal-shaped pixels
* PMT XP1911: window of DIA 15 mm
* Winston cone: 30 mm input size, 15 mm output
* FOV - 9.72x9.72°, angular size 0.36°per pixel

Mirror:

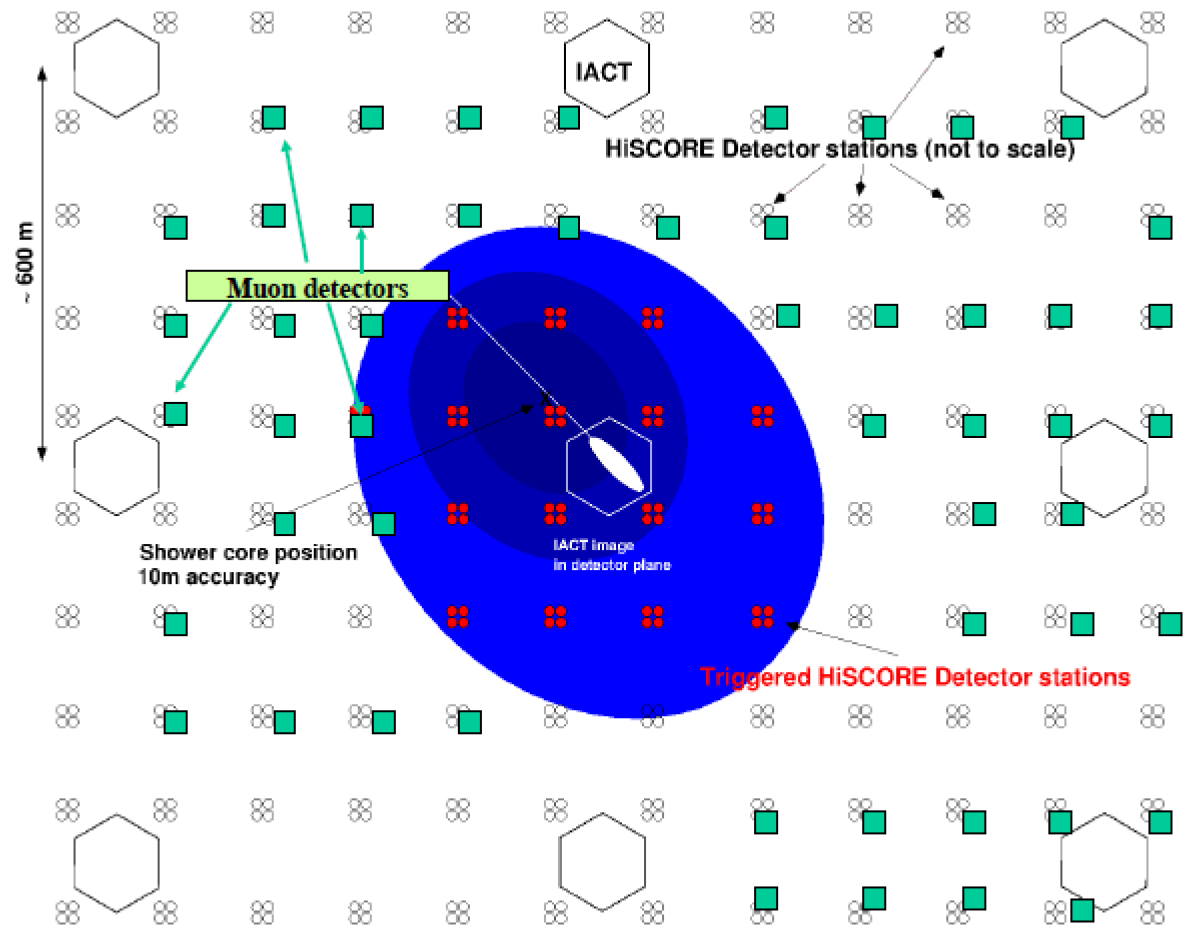
* Davies-Cotton optic type
* Focal length: 4.750 m
* 34 spherical mirror segments
* Diameter of each segment: 60 cm
* Diameter of the mirror: 4.3 m
* The area: ~10 m^2

TAIGA - HiSCORE:
core position, direction, energy reconstruction.

Gamma/ hadron separation

TAIGA-IACT:
image form, monoscopic operation

TAIGA-Muon:
electron/muon ratio



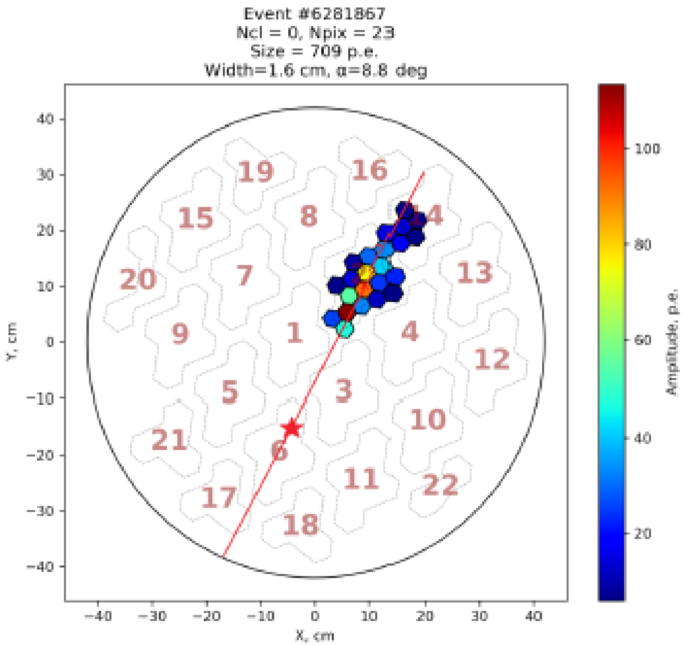
Combined approach of the imaging and timing techniques: inter telescope-distance can be significantly increased!

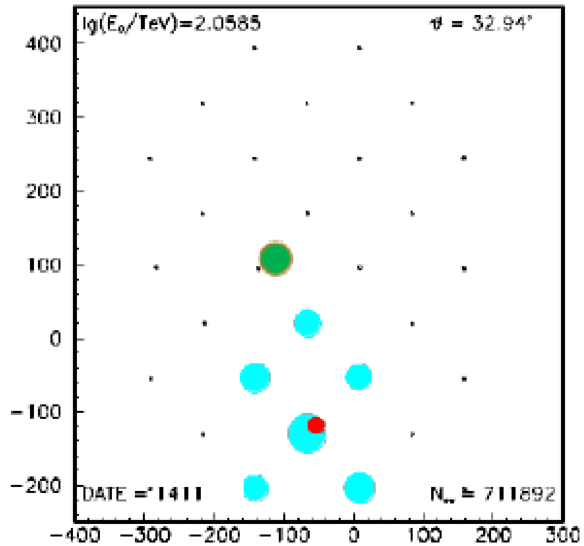
Joint operation of HiSCORE + IACT

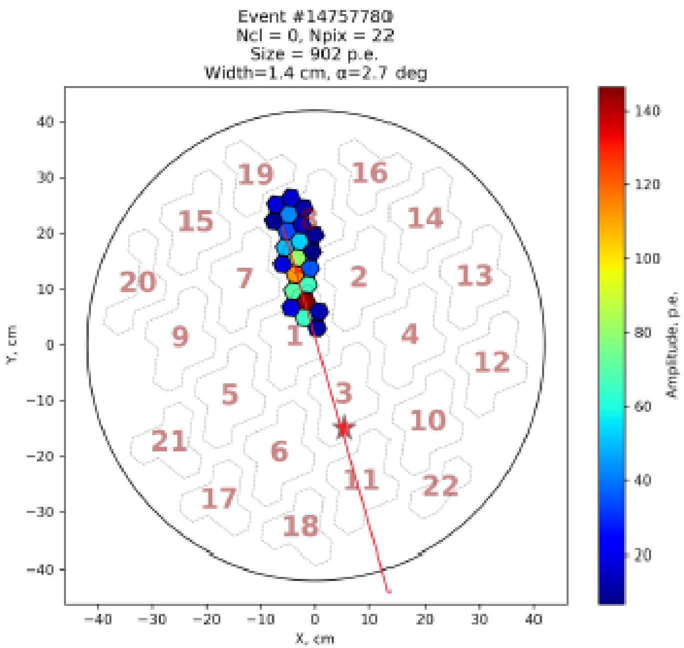
* Joint events with low energy are selected from source direction
* Axis, core and energy is taken from HiSCORE
* Quality cuts base on CORSIKA simulations are applied to IACT reconstruction

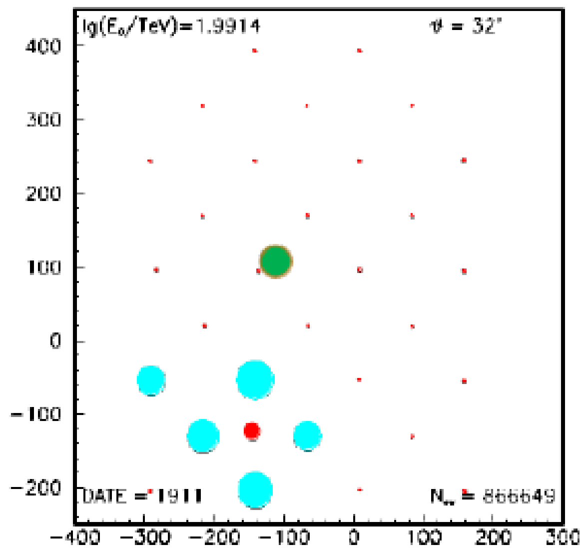
* First observation period was about 20 h long (Crab + Mrk-421)
* About 15k joint events were recorded
* 3 gamma candidates survived during this period after quality cuts

First gamma candidates

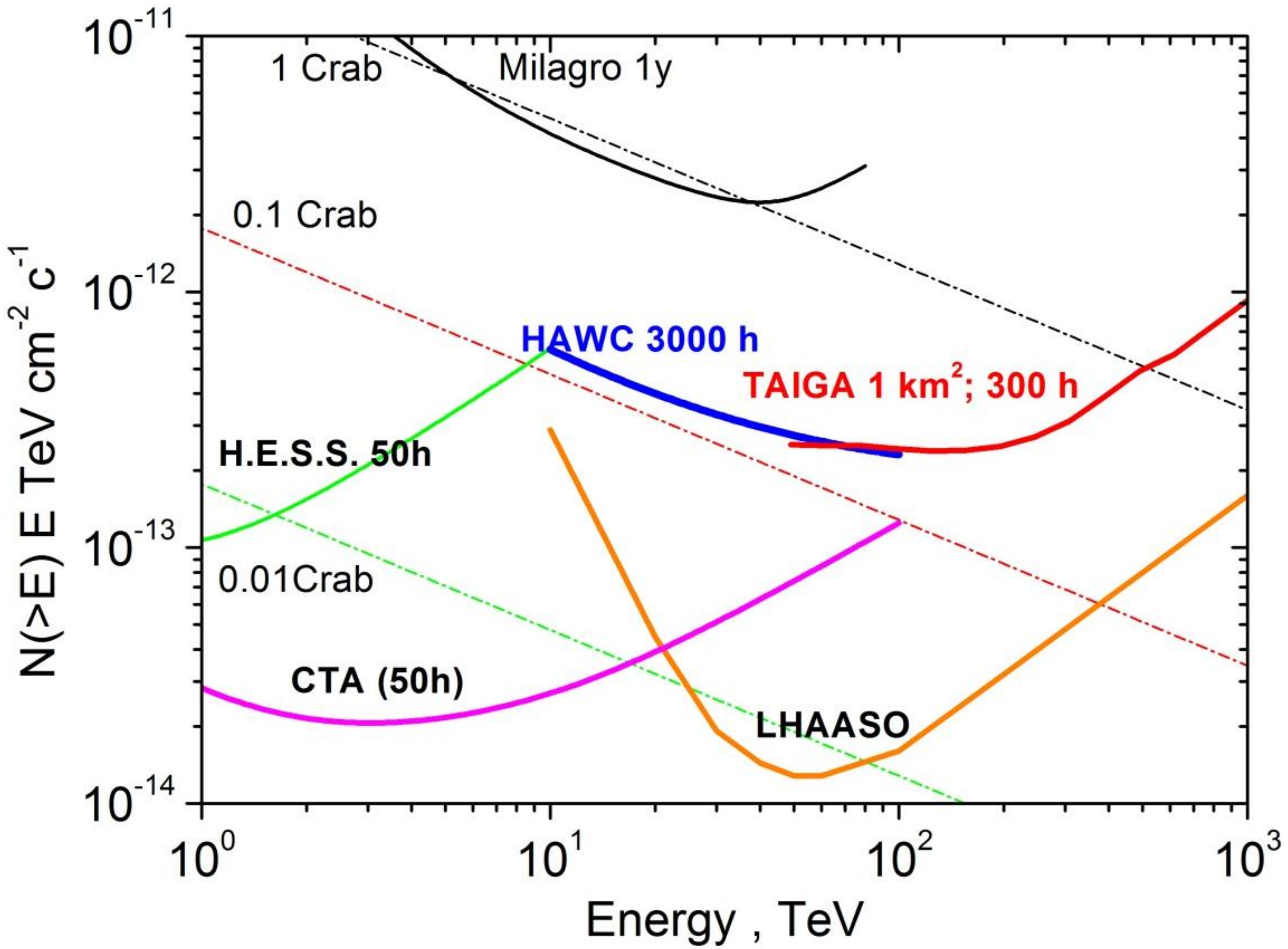








TAIGA-HiSCORE and TAIGA-IACT point source sensitivity



* Point-source survey sensitivity for TAIGA at 300 h of exposure.

* TAIGA covers the continuation of the spectra of known Galactic sources, some of which might be the so far undiscovered Galactic cosmic ray PeVatrons.

Summary

* Tunka facility (TAIGA) is modern instrument with long history focused on cosmic rays and gamma astronomy

* Energy spectrum and mass composition of cosmic rays are measured in range of $10^{14,5}$ – $10^{18,5}$ eV

* TAIGA is equipped with leading radio detector (Tunka-Rex) which develops and tests new methods for next-generation sparse radio arrays

* TAIGA gamma instruments will be able to study UHE gamma sky

* Location of TAIGA allows one to study gamma sources almost non-available for other instruments (e. g. Tycho SNR)

* Next year will be equipped with 3 IACTs with a final goal of 16 IACTs