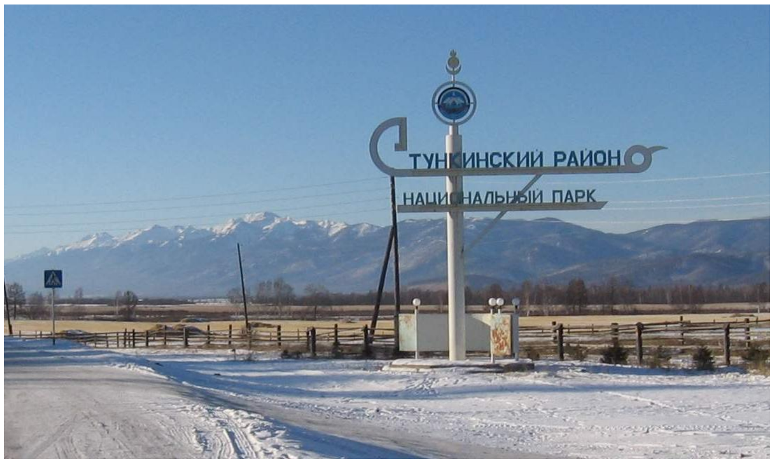
Cherenkov EAS Arrays in the Tunka Astrophysical Center: From Tunka-133 to the TAIGA Gamma- and Cosmic-Ray Hybrid Installation

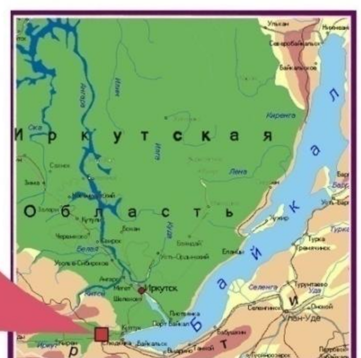
L.Kuzmichev (SINP MSU)
on behalf of the TAIGA Collaboration

WASDHA-2018, 18.09 2018

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



Tunka Valley, Republic Buryatia
- 50 km to west
from Lake Baikal.



51° 48' 35" N
103° 04' 02" E
675 m a.s.l.

The main aim of TAIGA project:

Study of very high energy (>30 TeV) gamma rays from Galactic accelerators with large area array (~10 km^2)

TAIGA - collaboration

Germany

Hamburg University(Hamburg)

DESY (Zeuthen)

MPI (Munich)

Italy

Torino University (Torino)

Romania

ISS (Bucharest)

Russia

MSU (SINP) (Moscow)

ISU (API) (Irkutsk)

INR RAS (Moscow)

JINR (Dubna)

MEPhI (Moscow)

IZMIRAN (Moscow)

BINR SB RAS (Novosibirsk)

NSU (Novosibirsk)

ASU (Barnaul)

Content of report

1. The main results of CR experiments in Tunka Valley

2. High energy gamma-ray astronomy and TAIGA project

3. TAIGA current status

4. The experiment in future

1. The main results of CR experiments in Tunka Valley

Cosmic rays and gamma ray with energy > 10^{15} eV

Tunka-133 -
175 optical detectors on the area of 3 km^2

Tunka- Grande –
380 scintillation counters for detection of
EAS charged particles

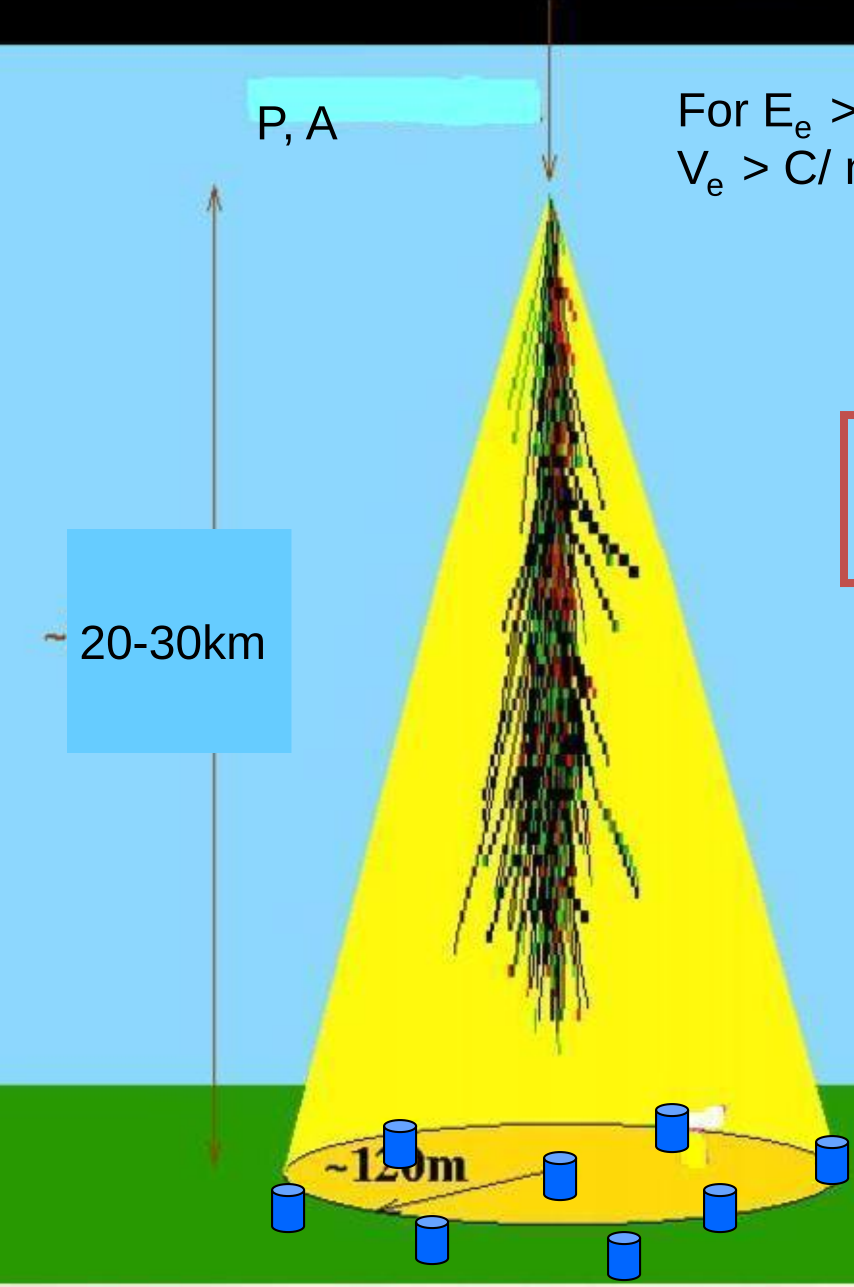
Tunka-REX – 64 antennas for detection of radio signals from EAS

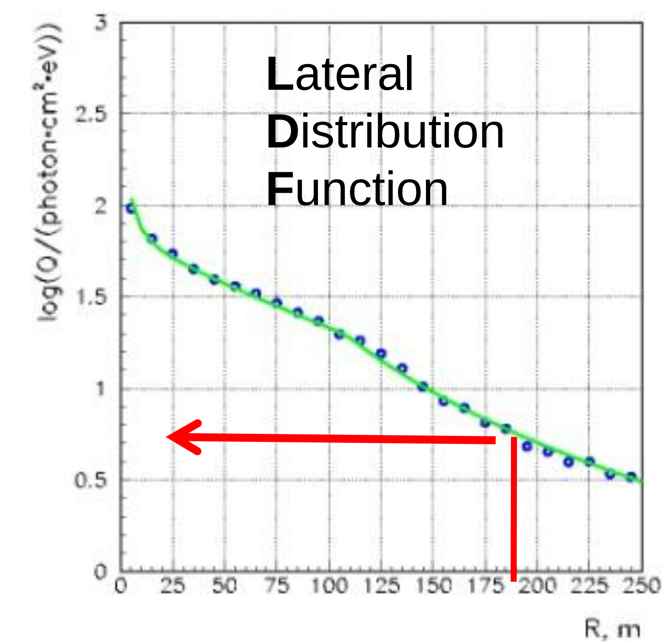
Atmosphere as
a huge calorimeter

For E_e >21 MeV (sea level)
$V_e > C/n$ – light velocity in air

Cherenkov light

$$Q_{tot} \sim \int N(x)\,dx \sim E$$



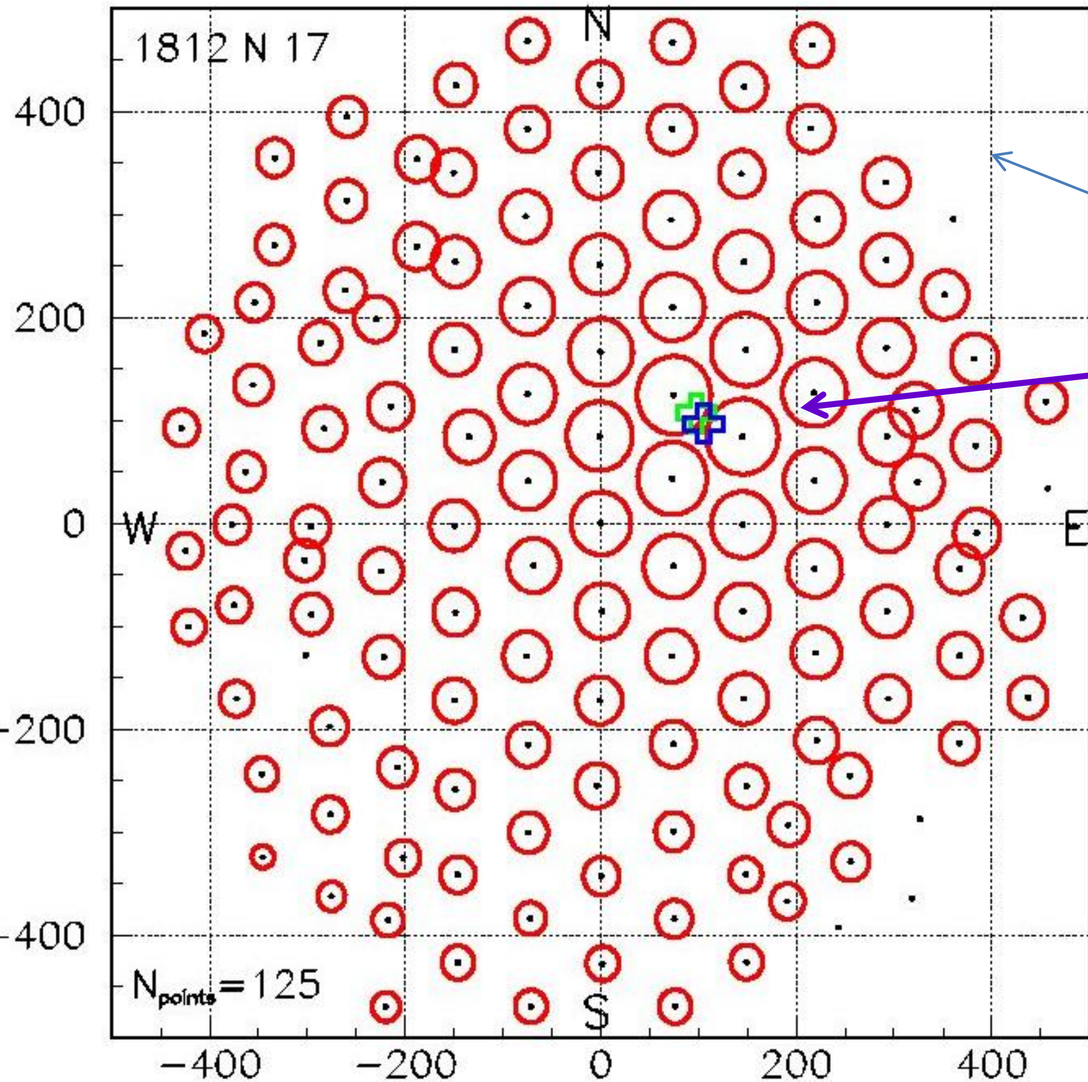


Photons detectors

E (PeV) = 0.4 Q(200) ph· ev^{-1} cm^{-2}

Example of event

Energy: $2 \cdot 10^{17}$ eV
zenith angle : 12.6 °



125 detectors

R ~ lg (I_{light})

Core position:

Energy determination:

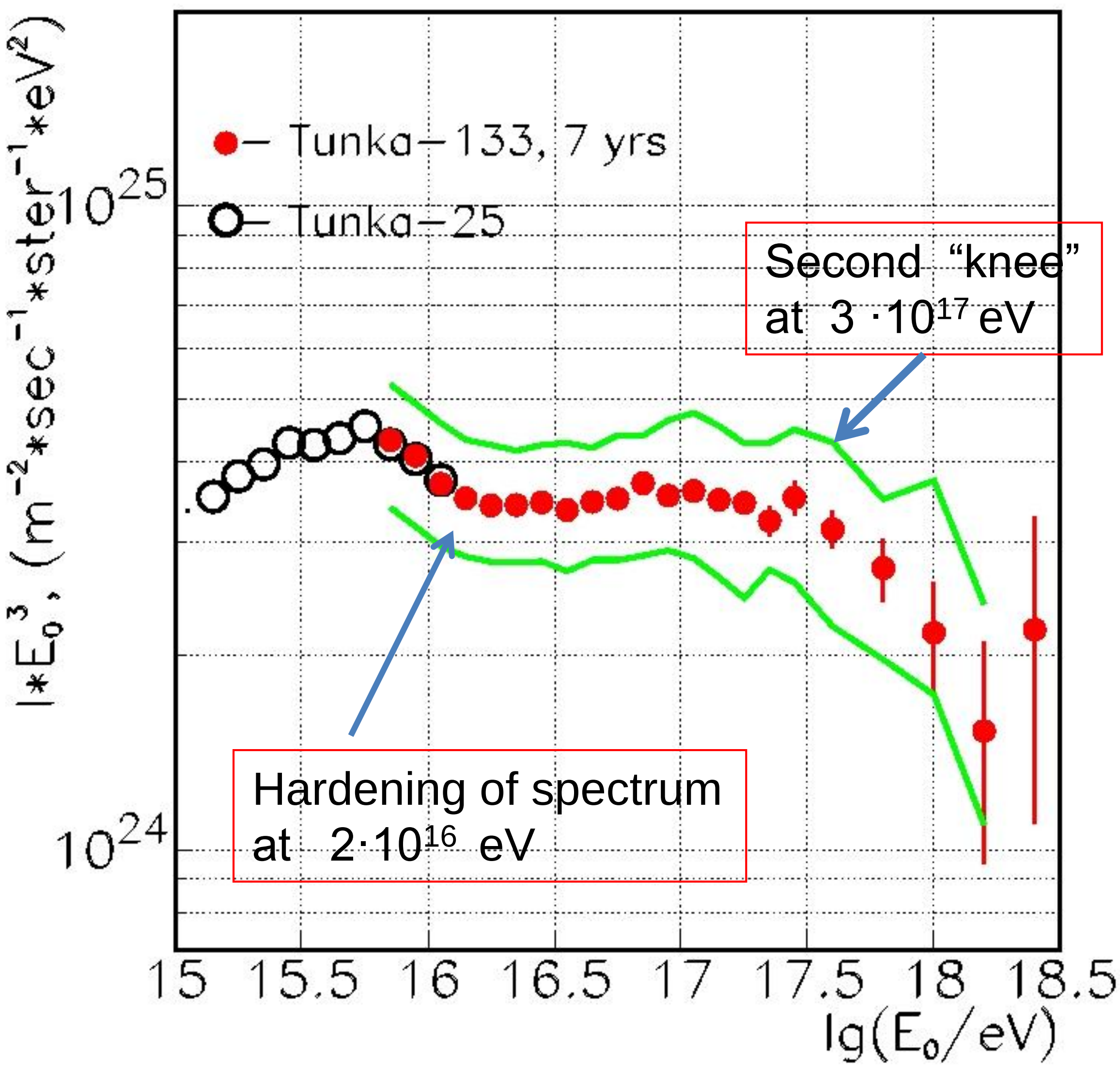
$$E = C \cdot Q(200)^{094}$$

Q(200) Cherenkov light density at 200 m from the shower core

Energy resolution ~ 15%

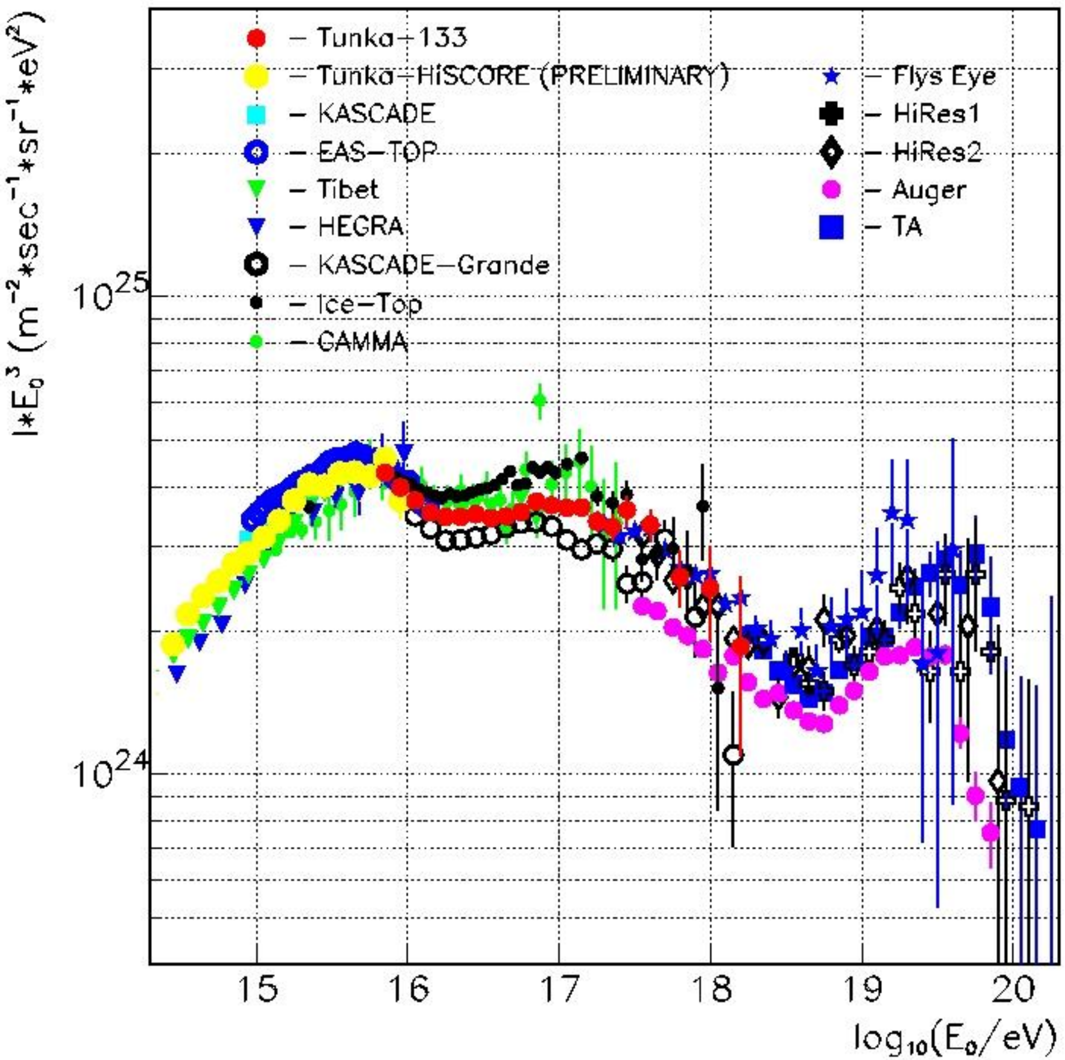
CR Energy Spectrum

2010 – 2017
352 nights
2200 h
~ 140000 – $E_0 > 10^{16}$ eV
4224 – $E_0 > 10^{17}$ eV
24 – $E_0 > 10^{18}$ eV



All particle energy spectrum

Flux × E ^{3}



2.High-energy gamma-astronomy and the TAIGA project

The TAIGA experiment - 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 large area installation is a joint operation of wide-field-of-view timing Cherenkov detectors (the *non-imaging technique) with a few cost efficient, small-size imaging Air Cherenkov Telescopes.*

The first stage of TAIGA - 1 km^2 area installation with 120 wide-angle timing detectors and 3 IACTs.
Commissioning of installation in 2019

The main methodical tasks for High Energy Gamma-ray Astronomy :

- select gamma EAS from the hadronic background EAS,
- determine with maximum accuracy the direction of the EAS from the gamma-ray

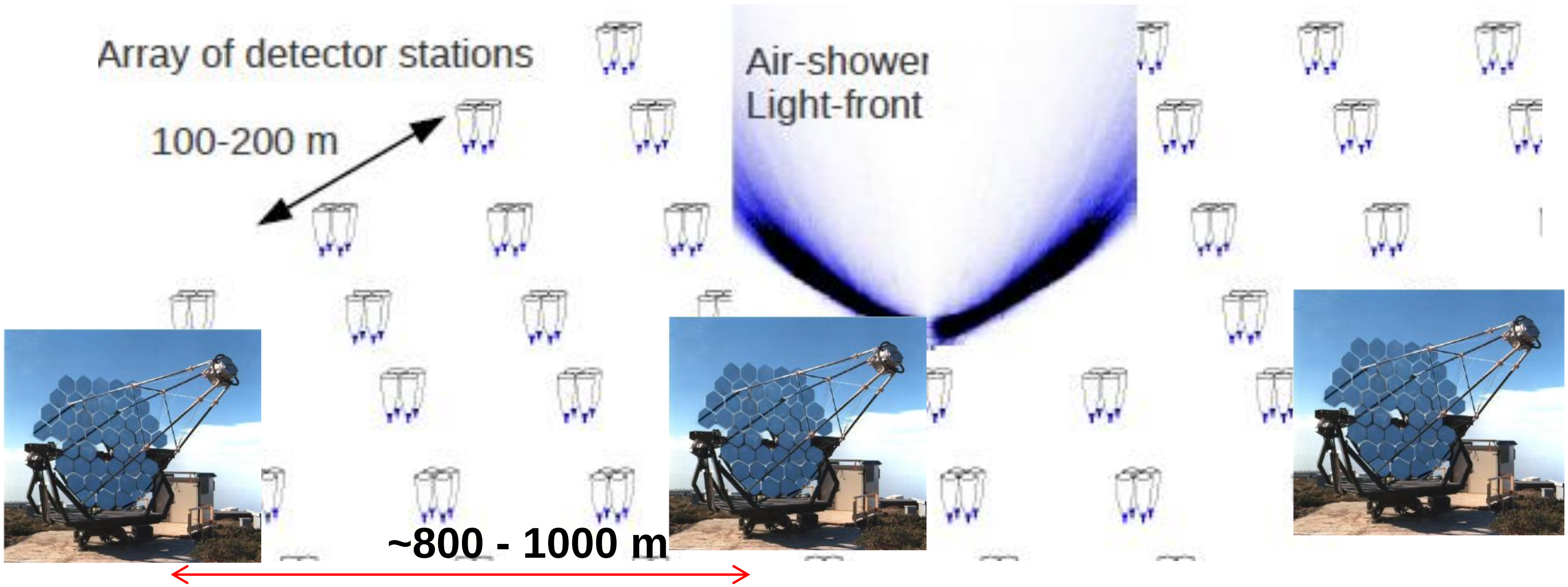
1. **Imaging technique : very high efficiency hadronic EAS rejection, relatively high cost of IACT**

2.. **Non-imaging technique (as the Tunka-133 array):**
   - **High angular resolution (~ 0.1°)**
   - **Low cost**
   - **poor hadron suppresion**

3. **Number of muons in EAS**
   In Gamma-EAS there are 30 times less muons than in Proton EAS

In TAIGA we plan to optimally combine all approaches

TAIGA : Imaging + non-imaging techniques



TAIGA - HiSCORE: core position, direction and energy
Gamma/ hadron separation - TAIGA-IACT (image form, monoscopic operation)

Scientific Program

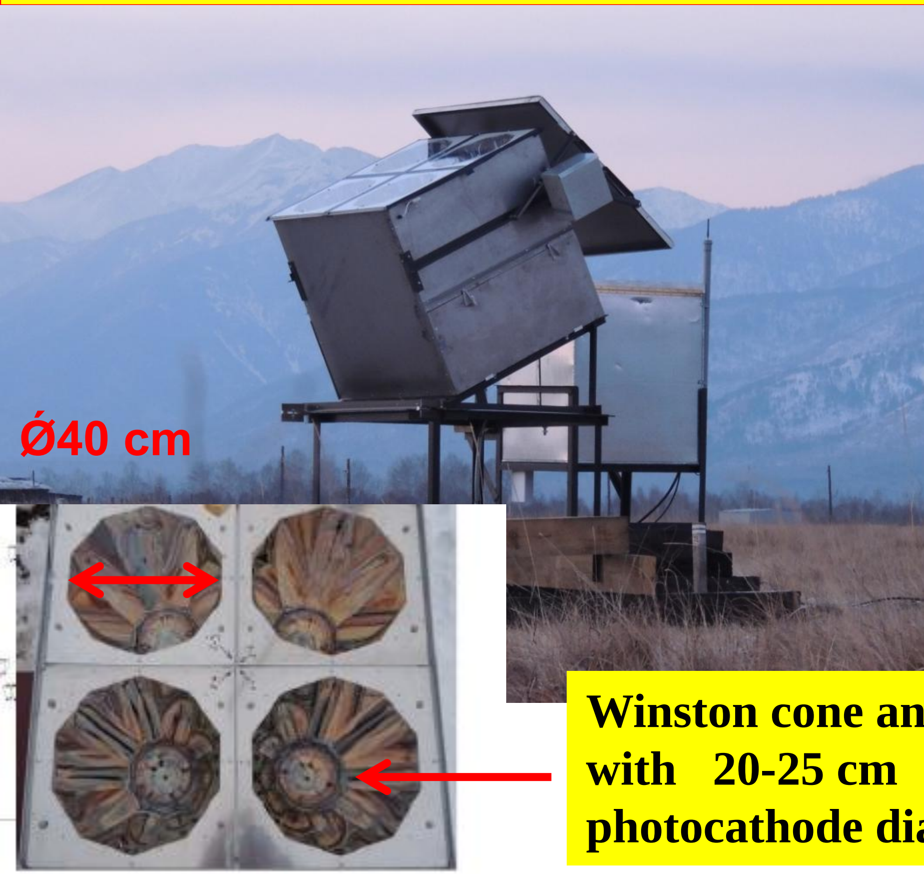
1. Study of high-energy edge of spectrum of galactic gamma-ray sources. Search for Pevatrons

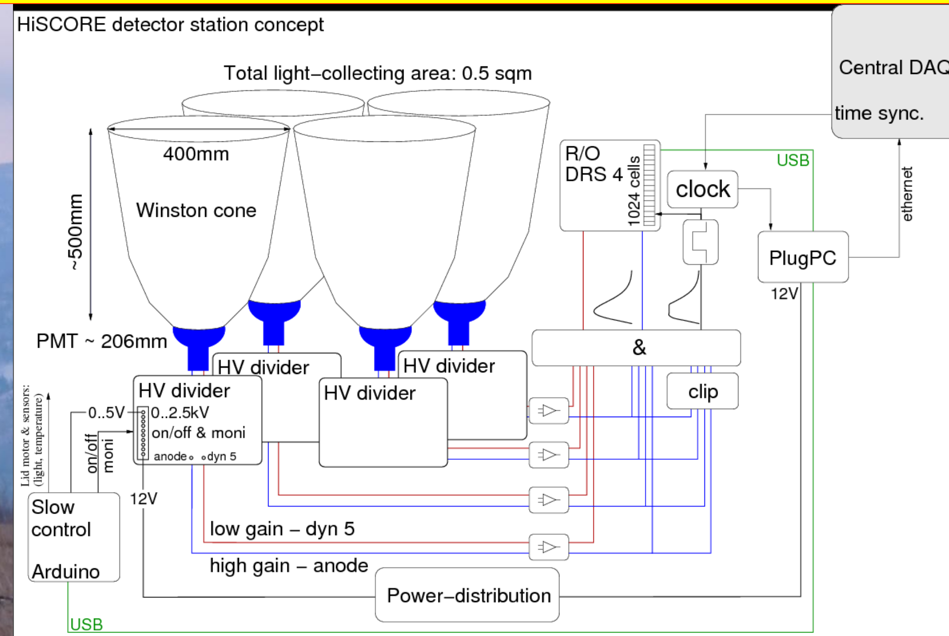
2. Monitoring of the bright extragalactic sources

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).

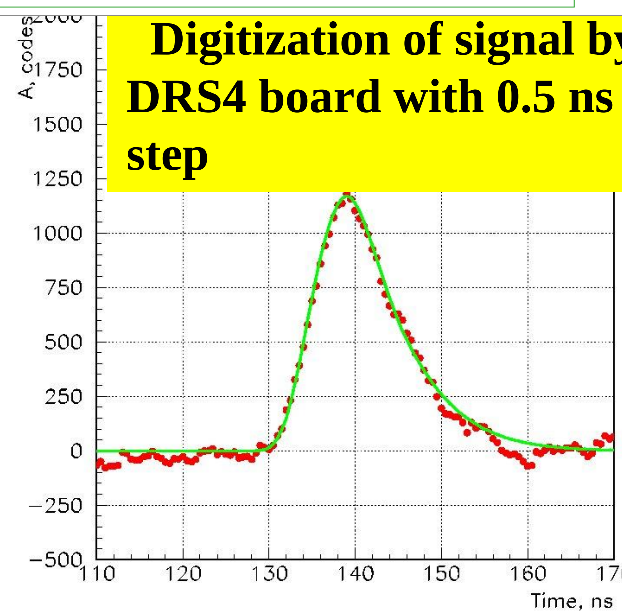
Wide angle station





Winston cone and PMT with 20-25 cm photocathode diameter

Digitization of signal by DRS4 board with 0.5 ns step

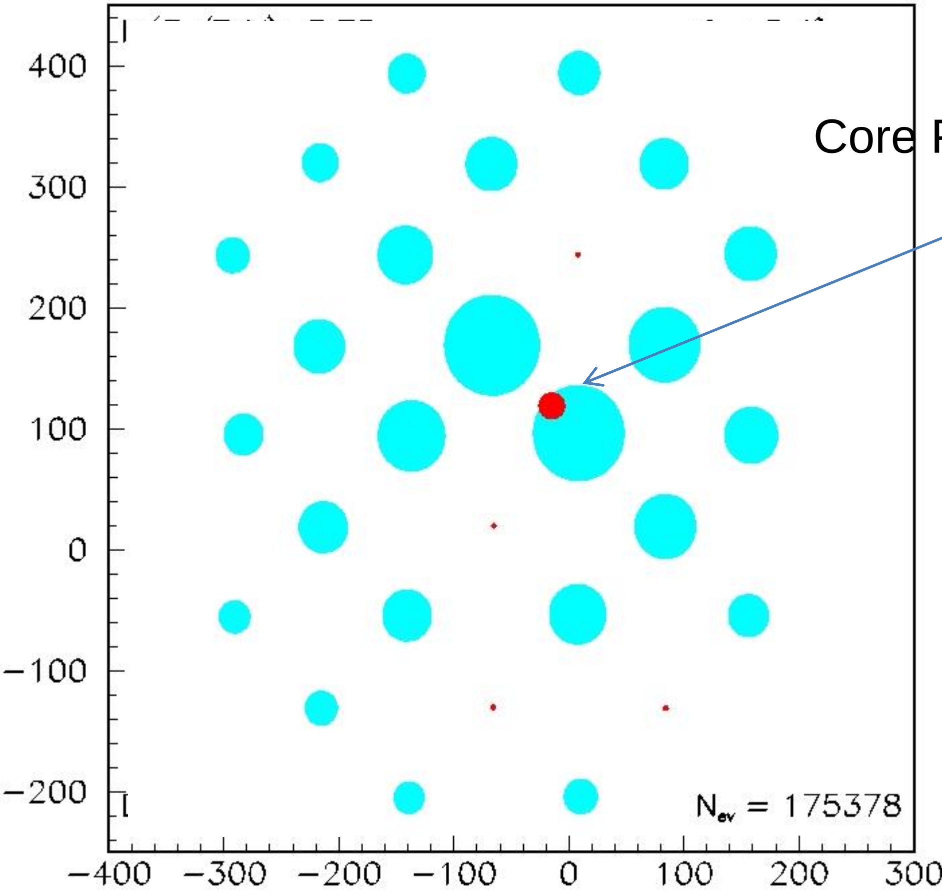


S tot = 0.5 m^2

(R5912, R7081, ET9352)

Synchronization and data taking via optical

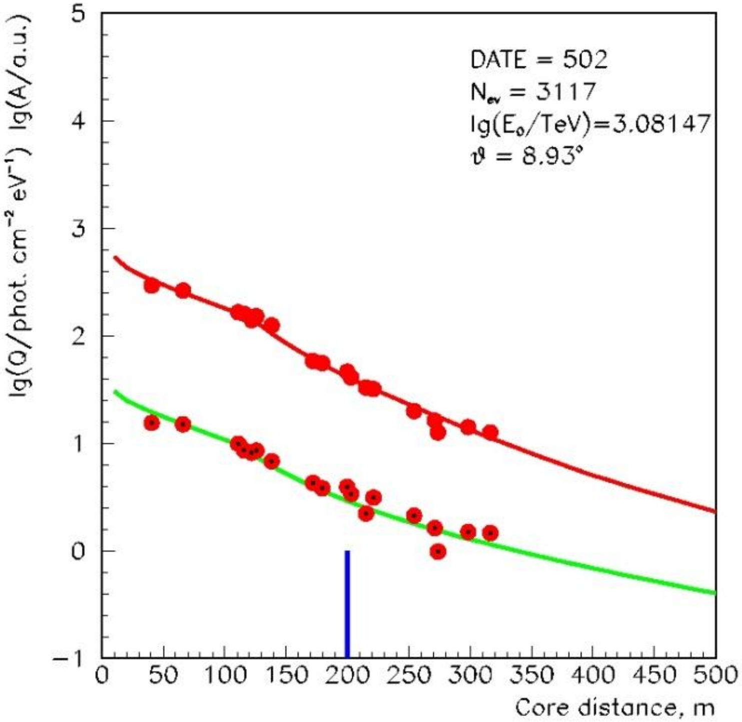
Event example



R ~ Lg (Photon flux)

Core Position

Lateral Distribution Function (LDF)



Energy determination:

E = C· Q(200)^{094}

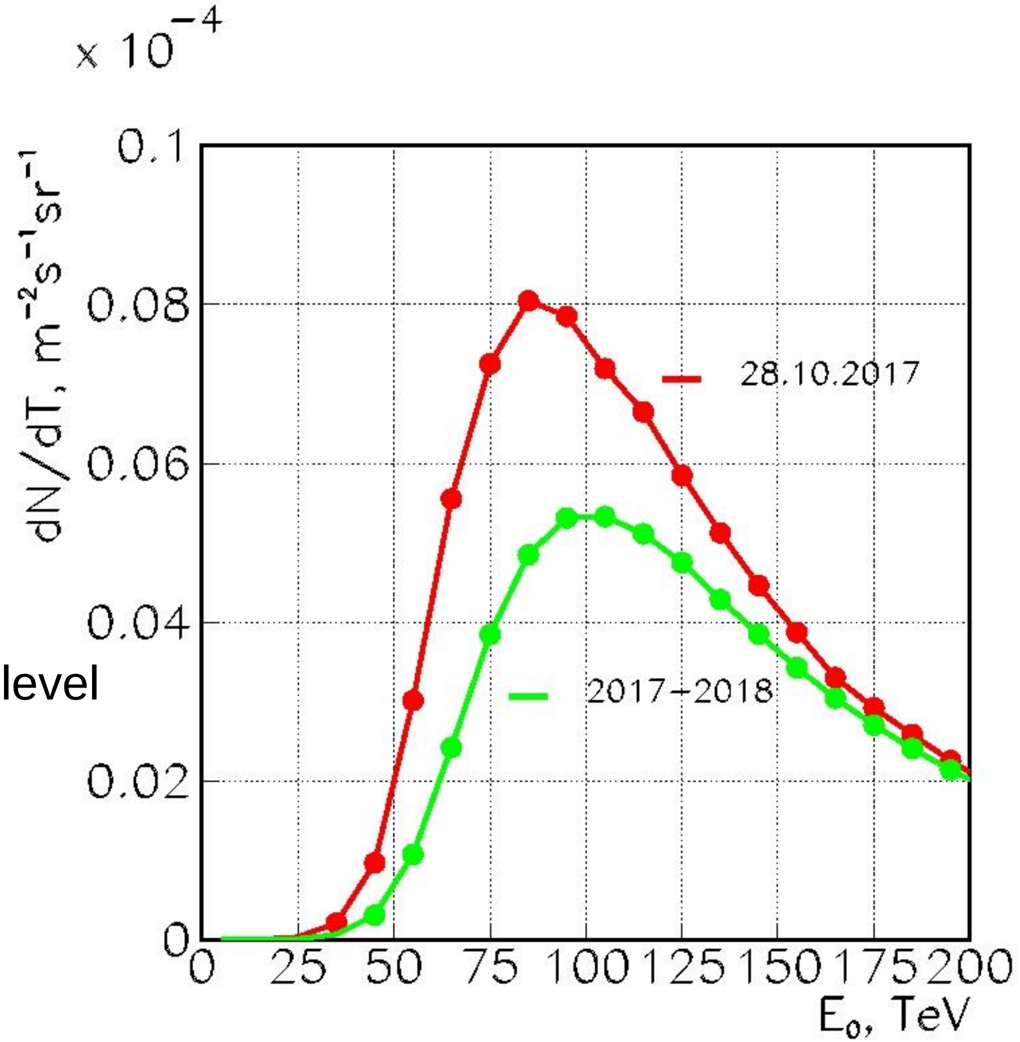
Energy Distribution for CR EAS

Maximum of energy distribution
for CR EAS 80- 100 TeV

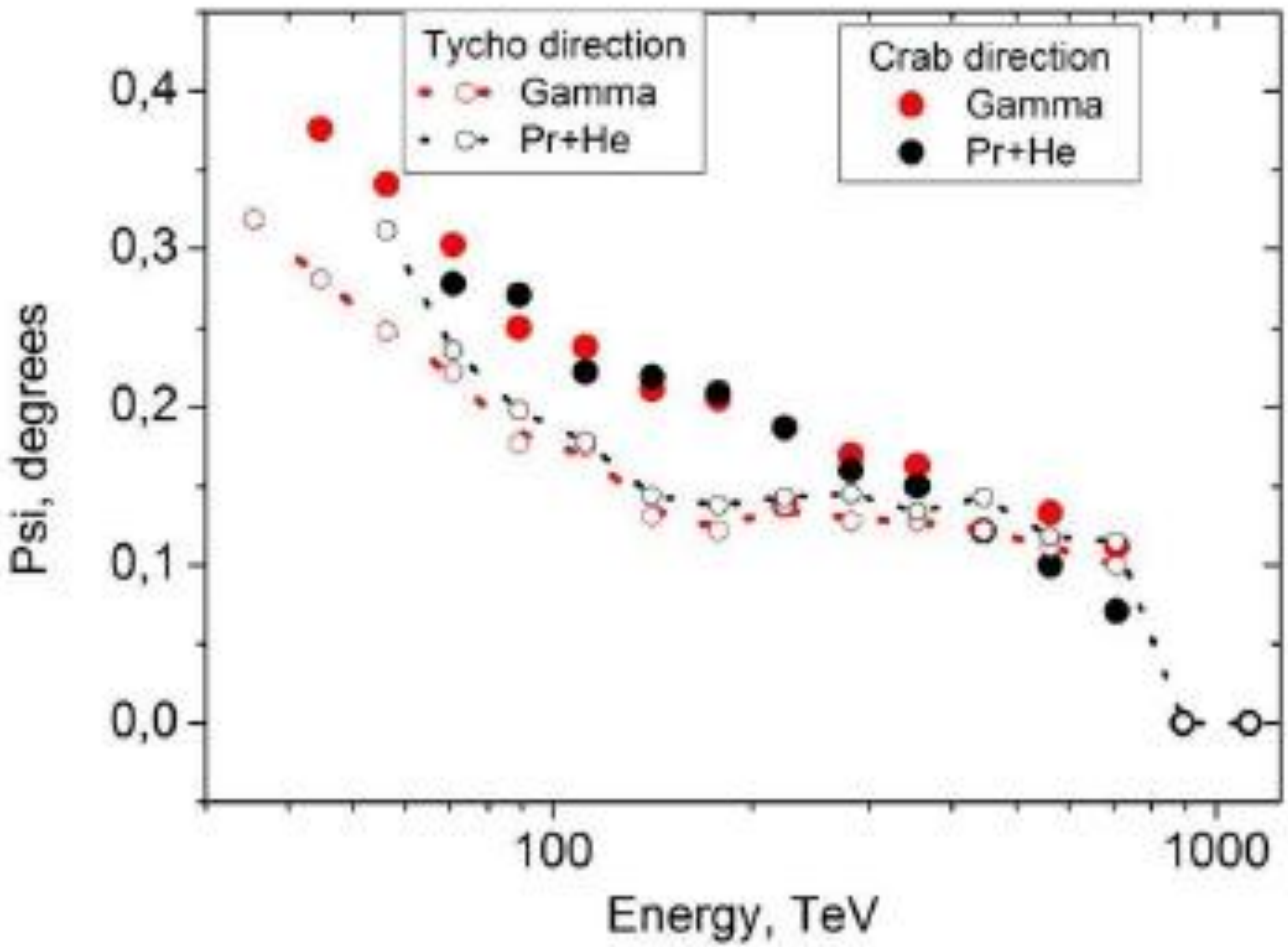
E gamma = E cr / 2

For gamma EAS - 40 – 50 TeV

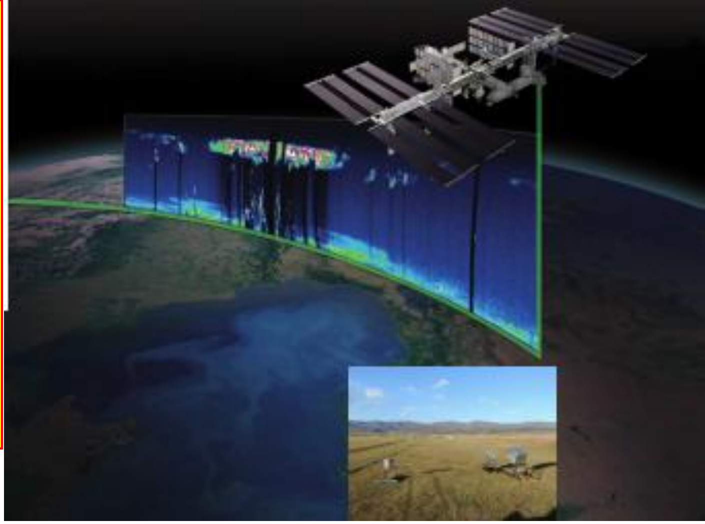
30 TeV at 2000 m above see level



Angular resolution

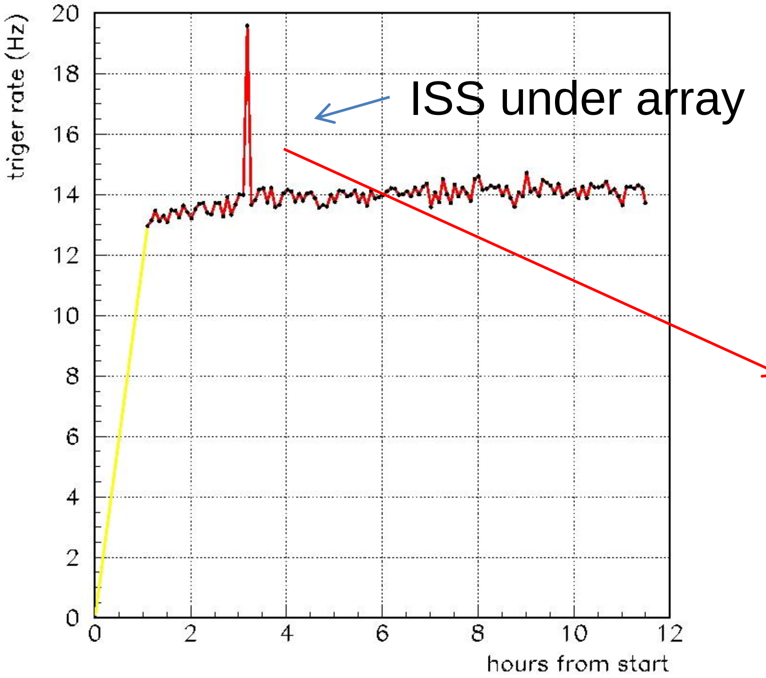


Light Source on board International Space Station (ISS) **(2016-2017)**

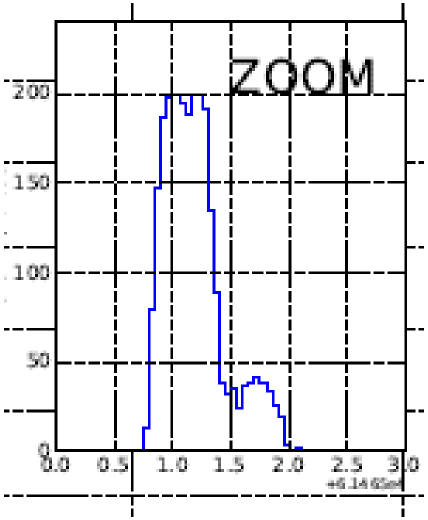


CATS (Cloud Aerosol Transport System) Lidar
532 nm, 4 kHz

Counting rate per 2 min (on-line data)

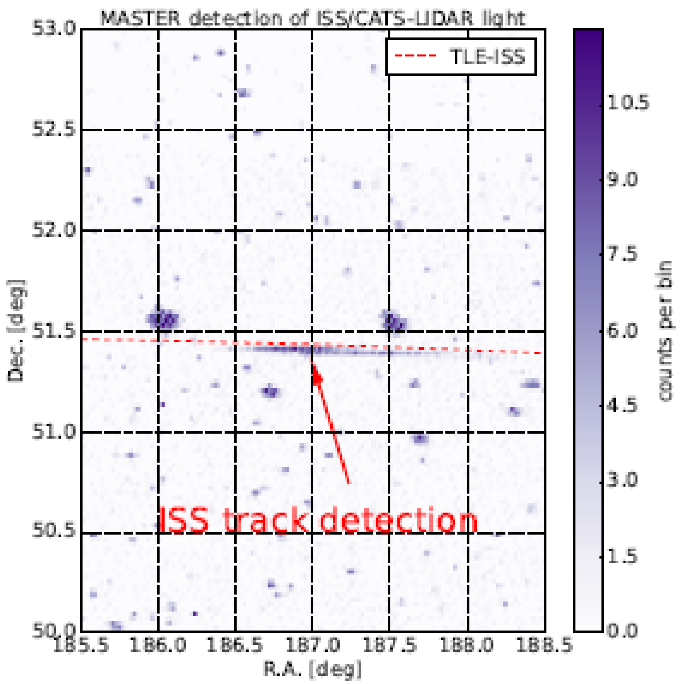


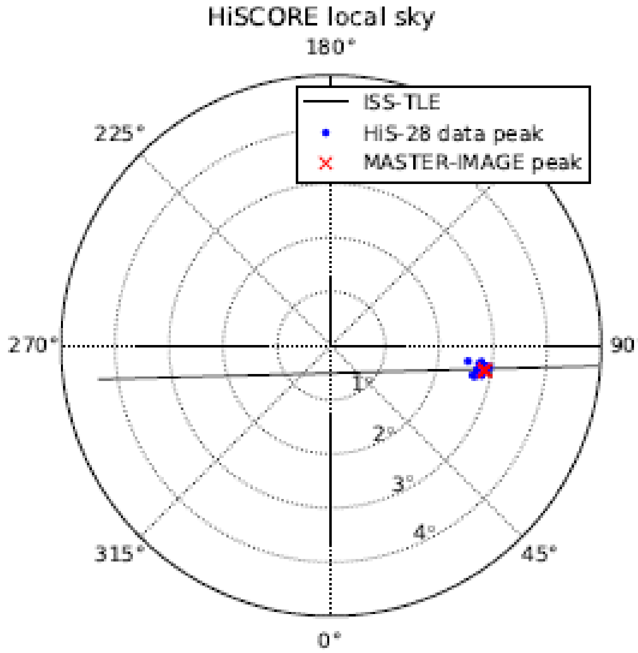
Events per 0.05 sec



- **Excellent HiSCORE calibration source**
  - **flat timing profile**
  - **precision pointing**

Common observation of ISS LIDAR by HiSCORE and optical telescope MASTER





Absolute pointing of HiSCORE $\alpha_{miss} \sim 0.1°$

TAIGA-IACT
(the Northernmost telescope)

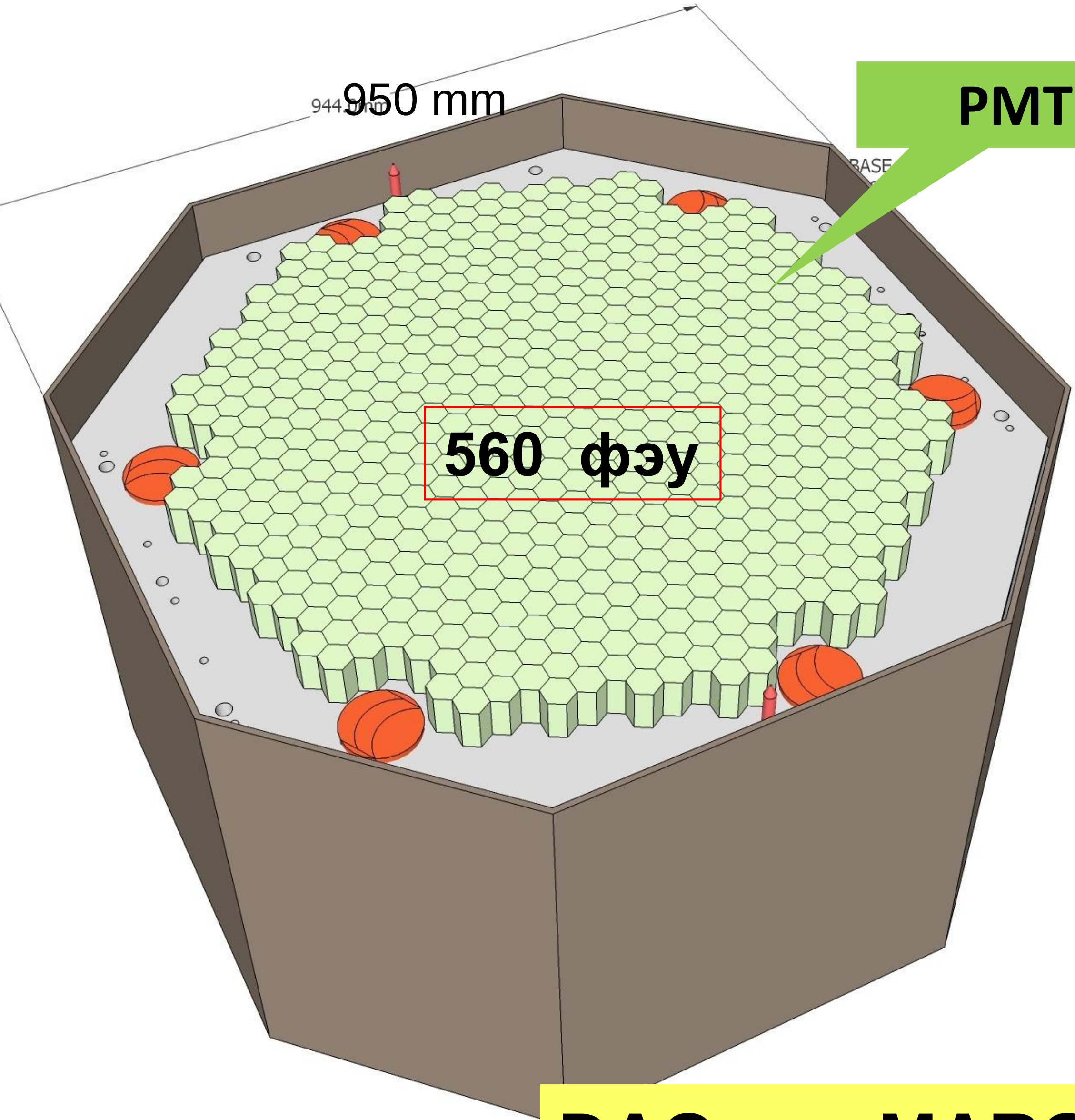
D = 4.32m F = 4.75m

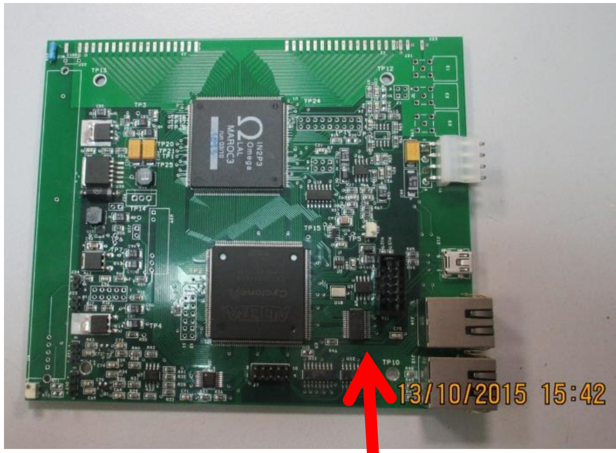
30 glass mirrors of 60 cm diameter

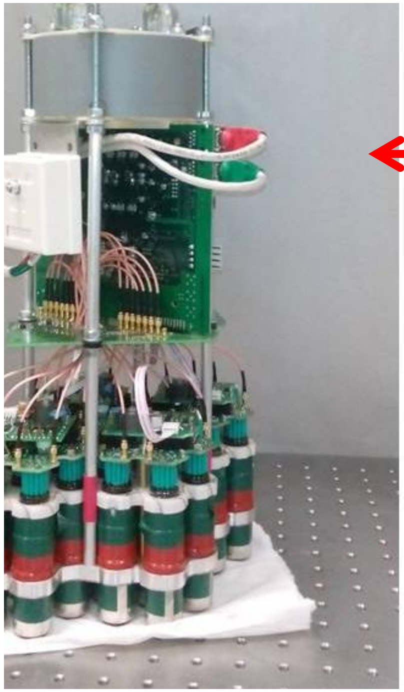
Camera : 560 PMTs (XP 1911) with 15 mm useful diameter of photocathode
Winston cone: 30 mm input size, 15 mm output size
aperture single pixel = 0.36°
FOV diameter ~ 9.6°

Energy threshold ~1.5 TeV

Camera of the TAIGA-IACT







Maroc-3
64 channel
board

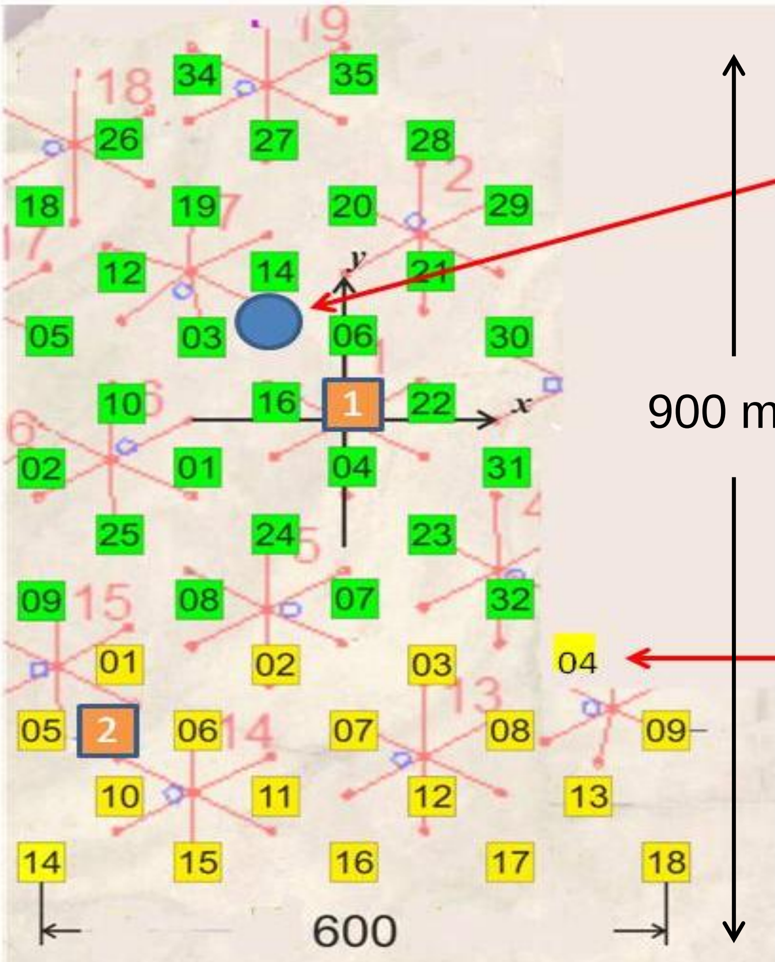
Cluster –
28 PMTs
22 clusters
per camera

DAQ - MAROC3


February, 2018

3. TAIGA current status

Season 2017-2018: layout parameters



IACT:
S of mirrors   8.5 m^2
Focus   4.75 m
FOV   9.5^o

HiSCORE stations:
43 stations

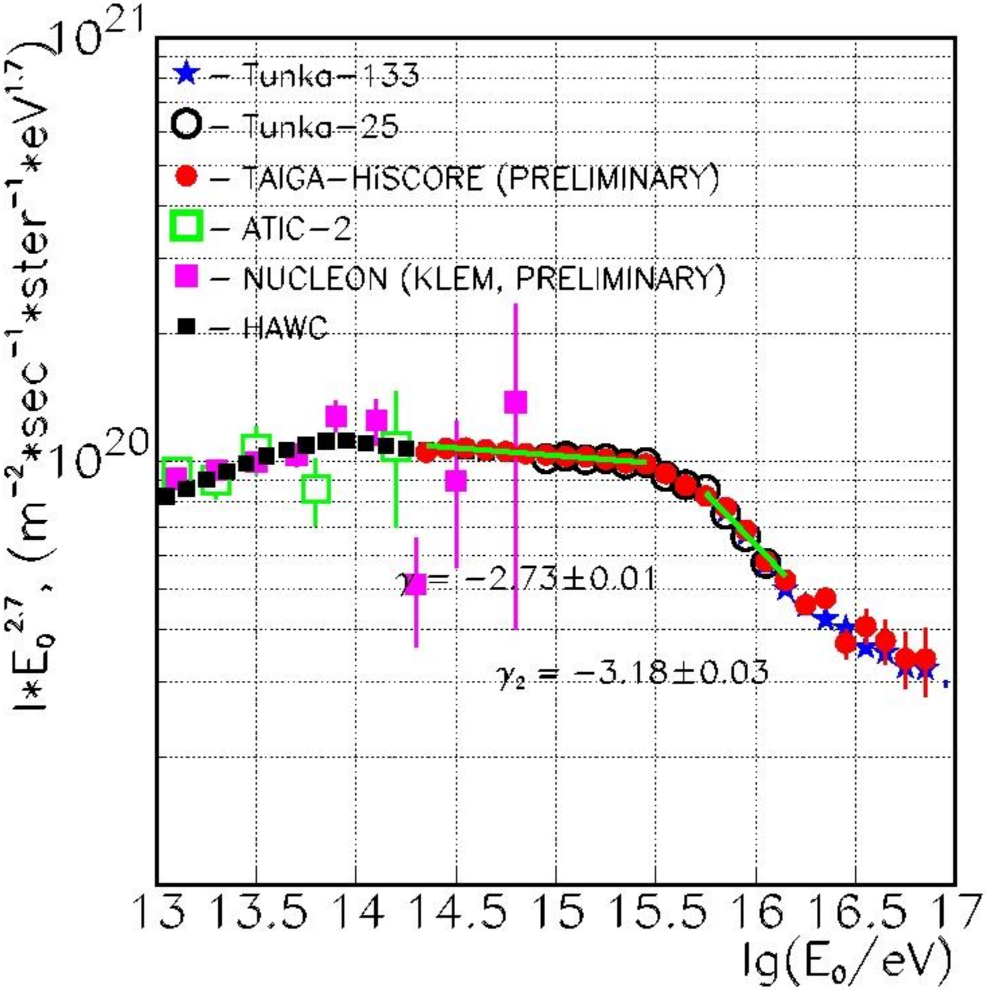
"Tilting" to the South at 25^o

Sub-ns array-wide
time synchronization

4 PMTs of 8'' size
with Winston cones
(light collection 0.5 m^2)
FoV ~0.6 sr

43 detectors , 106 m spacing,
S~0.5 km^2 (Only green stations were included in analysis)
S~0.25 m^2

CR energy spectrum 2018

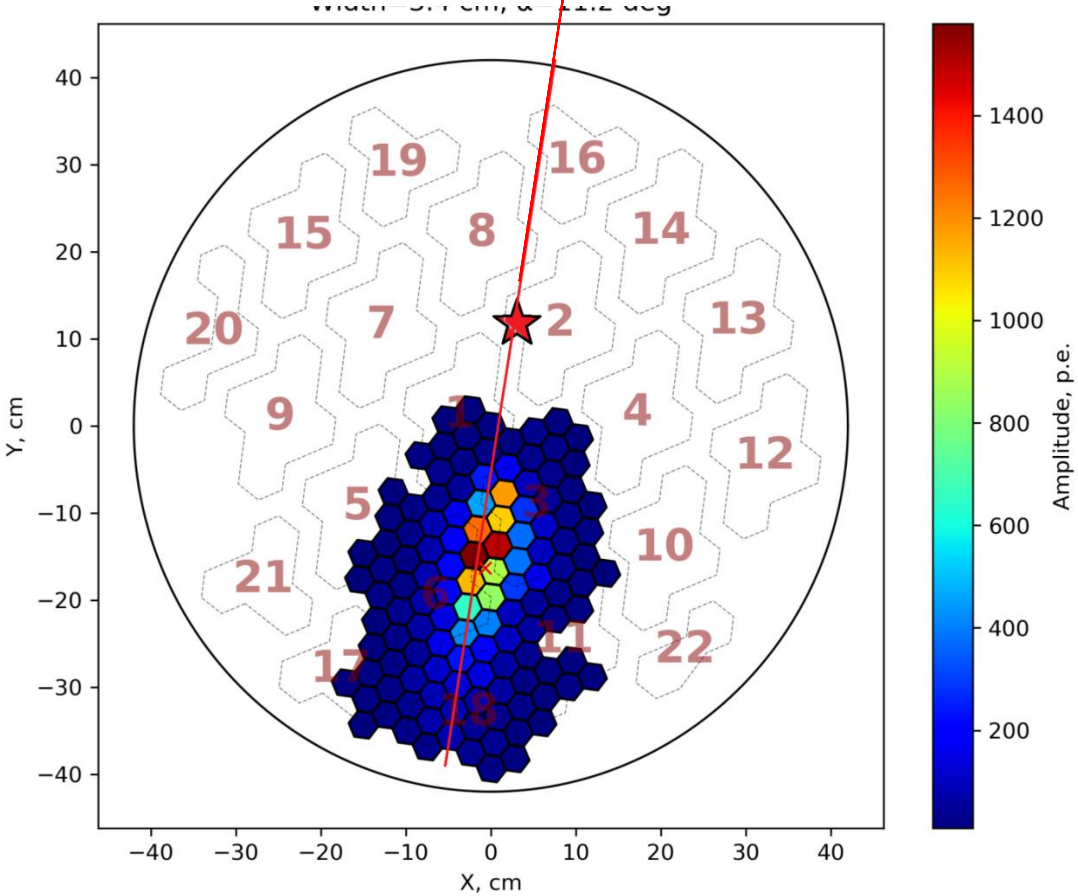


IACT and HiSCORE joint events

EAS core position

17000 joint events in 25 hours

~300 events in 0.7° around direction on Crab



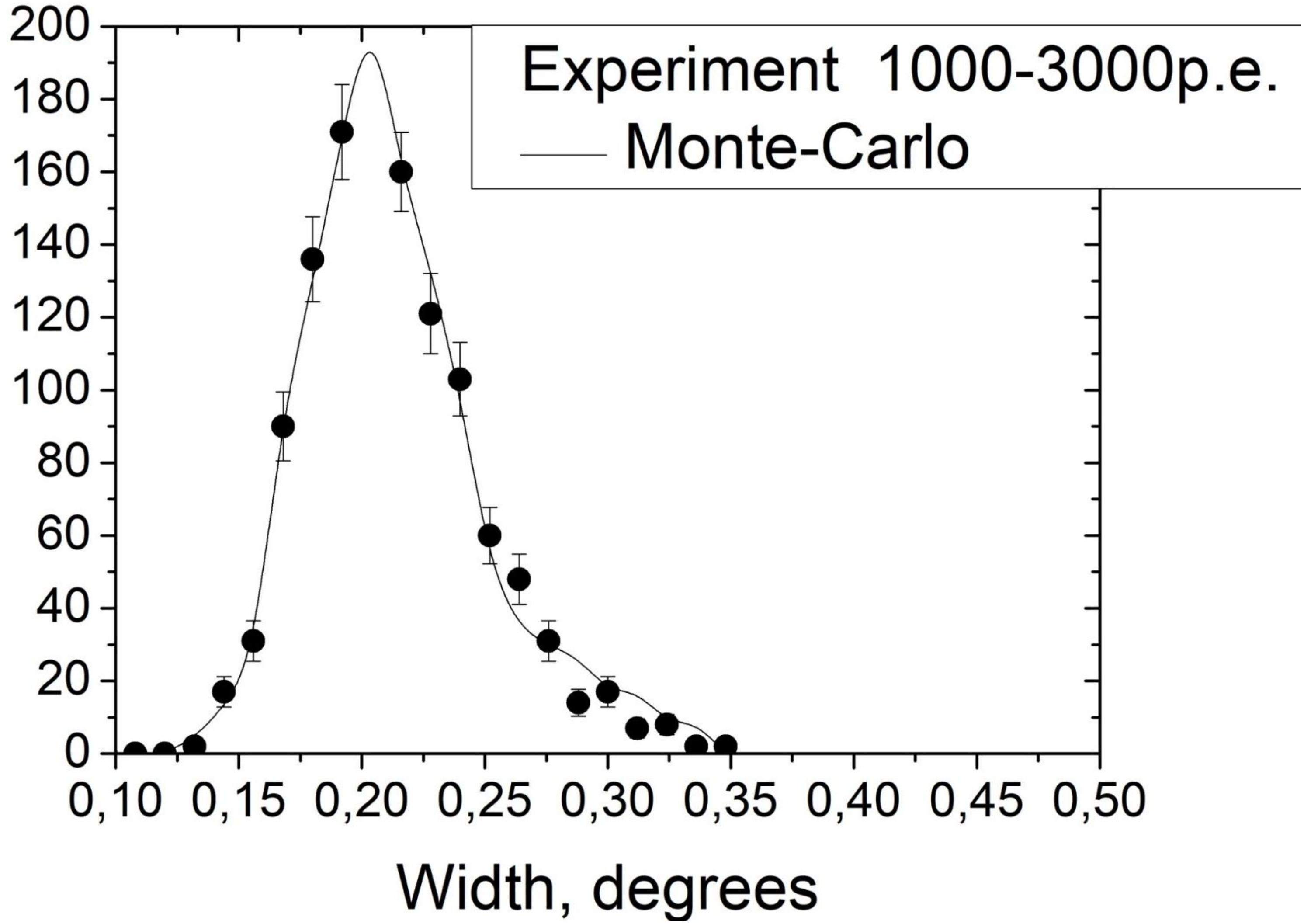
“Hadron –like” event

Hillas parameters of image:

Size = 18500 pe.
Width = 0.4° alpha = 11°

Energy from HiSCORE:
840 TeV

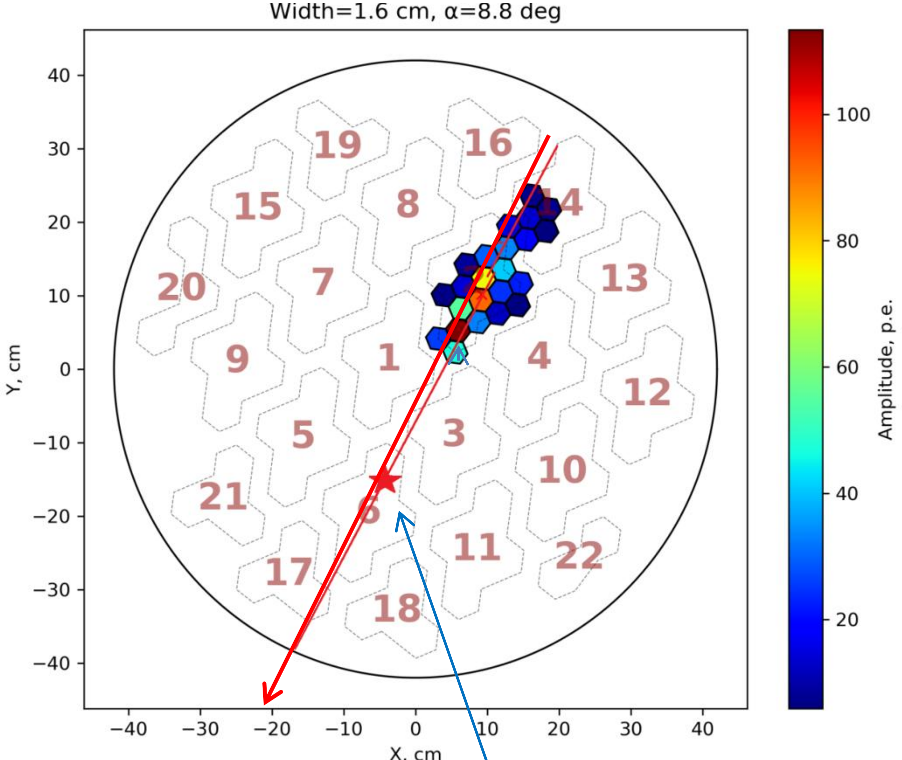
Width distribution : Experiment & MC



Example of hybrid "gamma-like" event

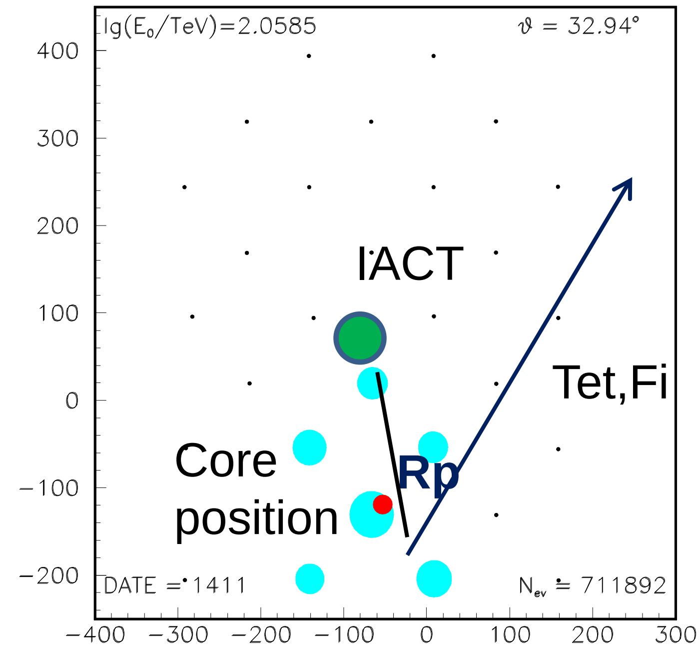
Width=0.13^o, length=0.69^o, alpha=8.9^o, size=709p.e.

HiSCORE data



E = 55 TeV

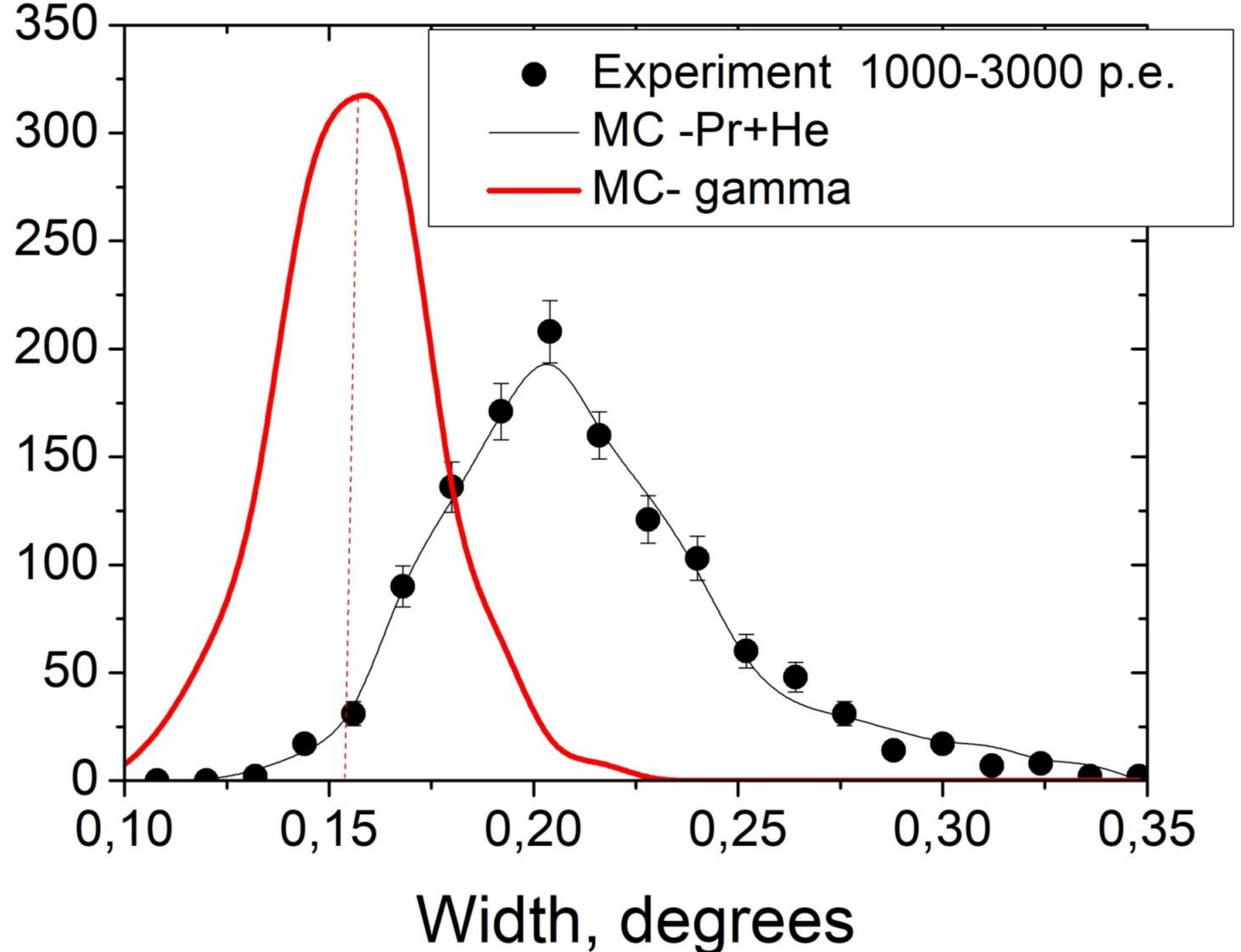
Tet = 32.9, Fi = 33. 58



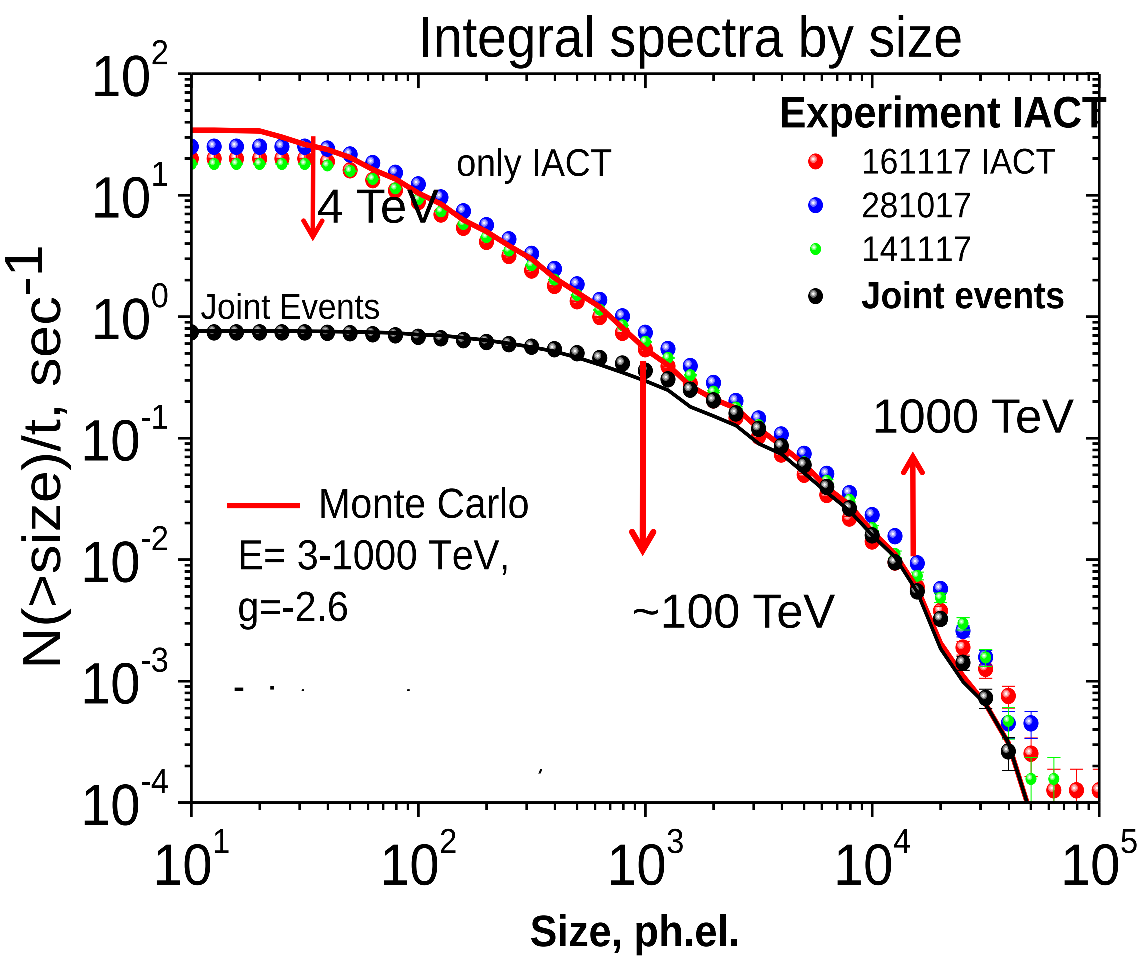
Recalculated core position in IACT plane after introduction of scaling factor Rp' = Rp/1500

IACT data

Width distribution : Experiment & MC

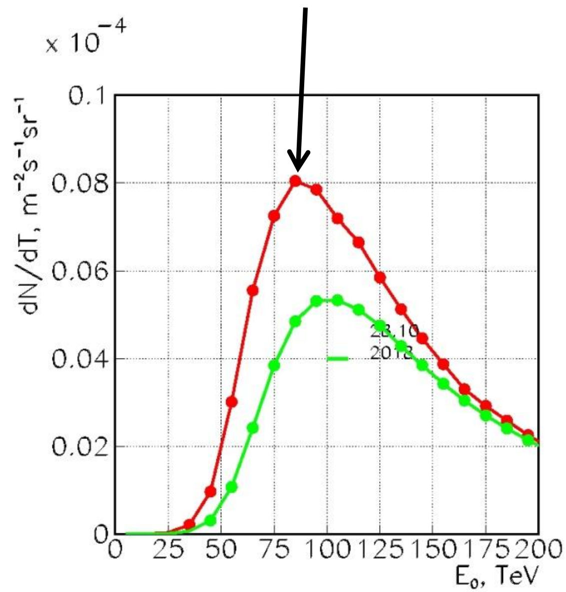


Integral spectra by size for the IACT events and joint events



HiSCORE energy spectra In linear scale

Peak energy
~100 TeV – CR
~ 50 TeV – gamma

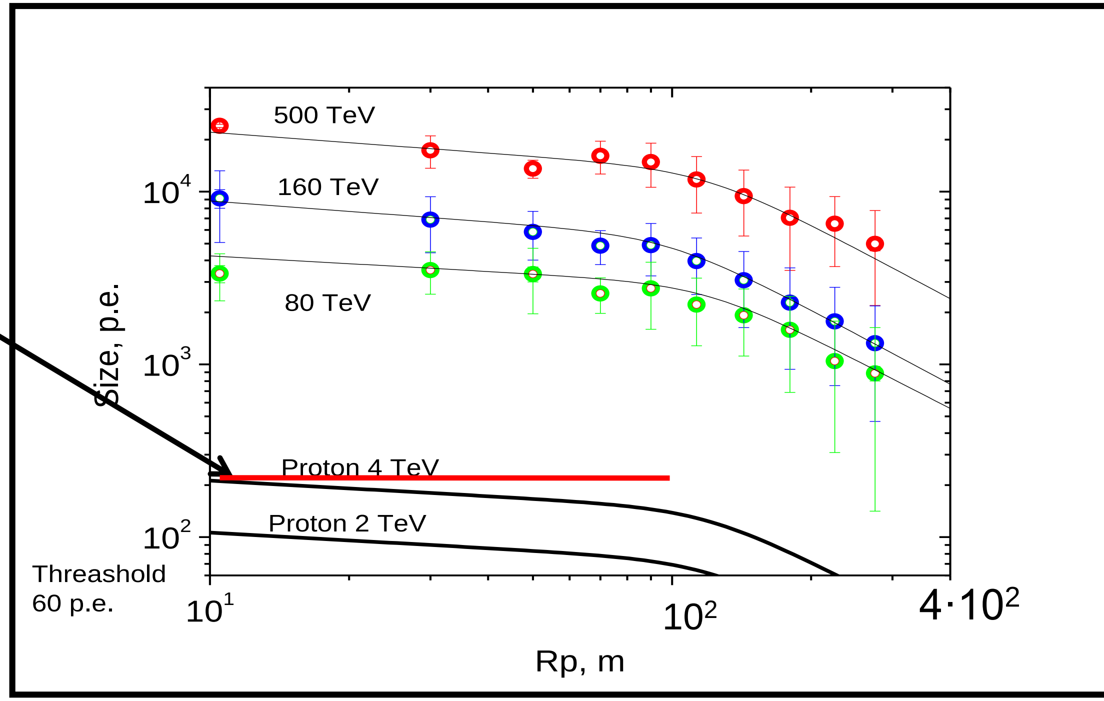


Size of image& distance from EAS core

Extrapolation from LDF at 80 TeV to LDF at 4 TeV and 2 TeV for protons
and estimation of LDF for gamma ~2 TeV

Eγ (TeV) ~ 100 p.e./100 up to Rp=150 m

Very preliminary



Rp - distance between EAS core and IACT

Monitoring of “Test” gamma-ray sources (CraB, Mrk-421) by the IACT in the stand-alone mode

Expectated observation time with 50% good weather time:

Crab - 130 hr

Mrk-421 - 120 hr

Tycho - 190 hr

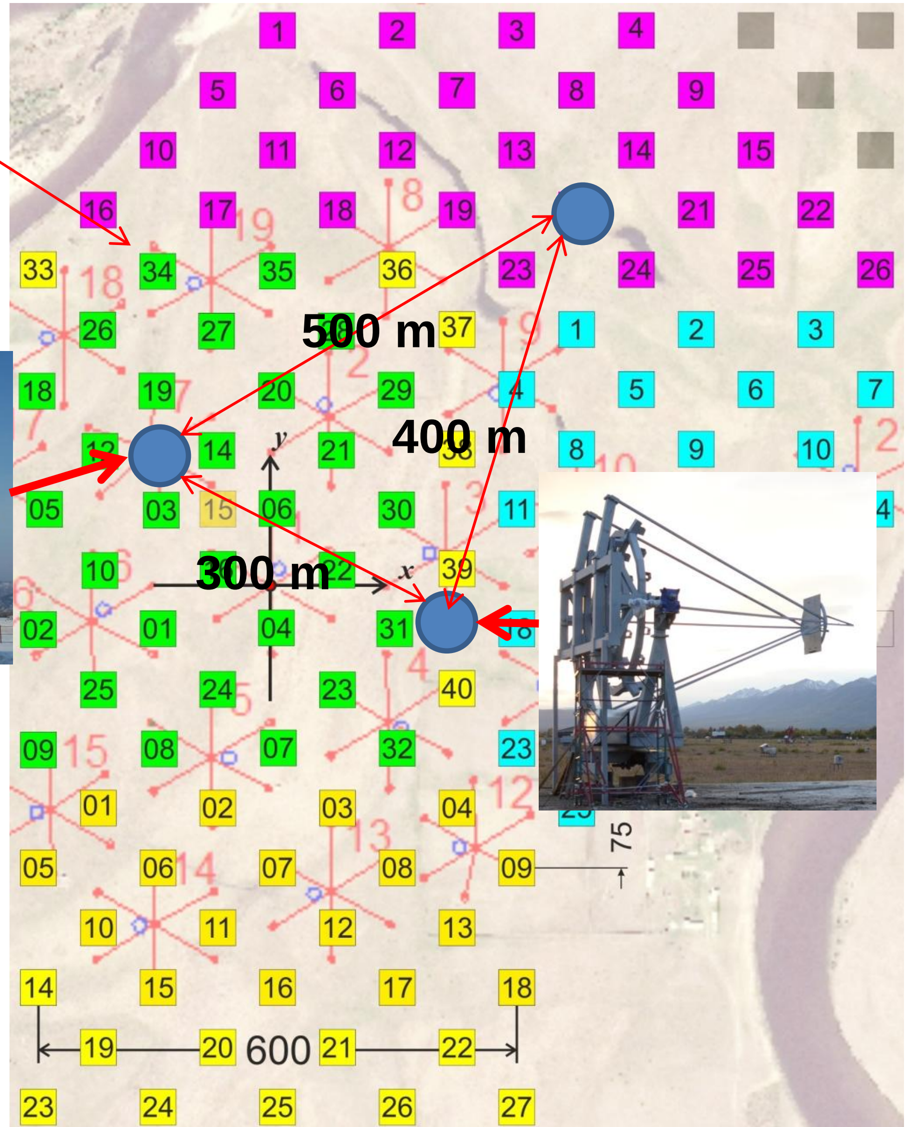
Due to abnormally bad weather during this season and a number of technical problems, the monitoring time of the "test" gamma sources (Crab, Mrk-421) was only about 25 hours.

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.

4. The future of experiment

Plan for 2018-19

120 stations



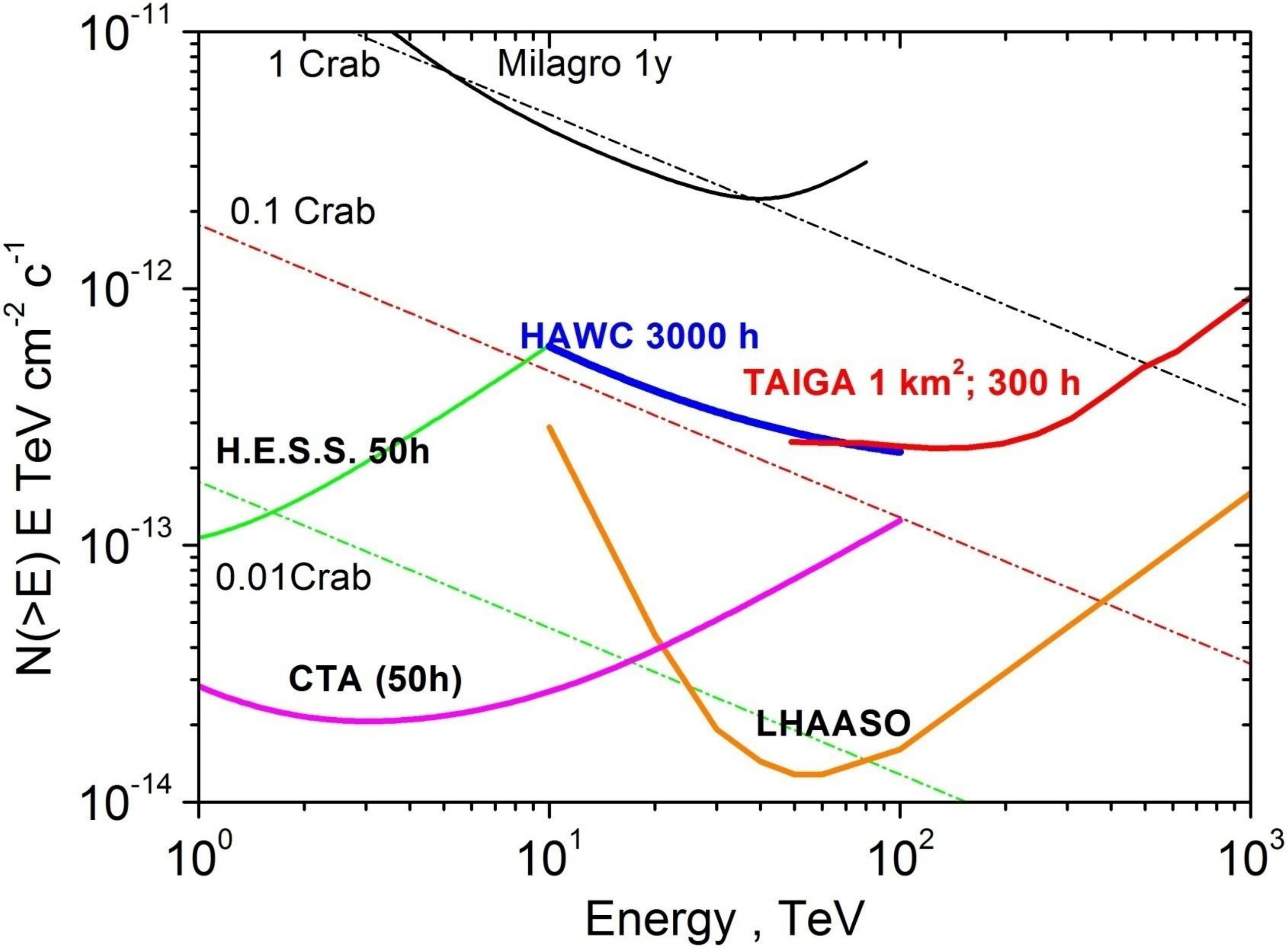
For 100 hours

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

50-100 hybrid events from Crab (E ≥.40 TeV)

Mirrors and camera
In April 2019

Integral sensitivity to local sources



Long term plan for TAIGA

- **1000 wide angle optical station on the 10 km^2 area, energy threshold 30 TeV**

- **15-20 IACTs (10 m^2 mirrors).**

•Muon detectors with total area 3.0 10^3 m^2.

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 -120 wide-angle stations and three IACTs is planned for 2019.

The expected sensitivity for 300 hours source observation with this array in the range 30 – 200 TeV is about **2.5 10^{-13} TeV/(cm^2 sec),** extending the energy range of existing and planned experiments to the ultra-high energy range.

3. The first commission seasons were successful:

- found out and removed bugs in hardware and software
- CR energy spectrum below the knee
- Lidar on board ISS – light calibration source for TAIGA
- First results from joint operation of HiSCORE and IACT

Thank you