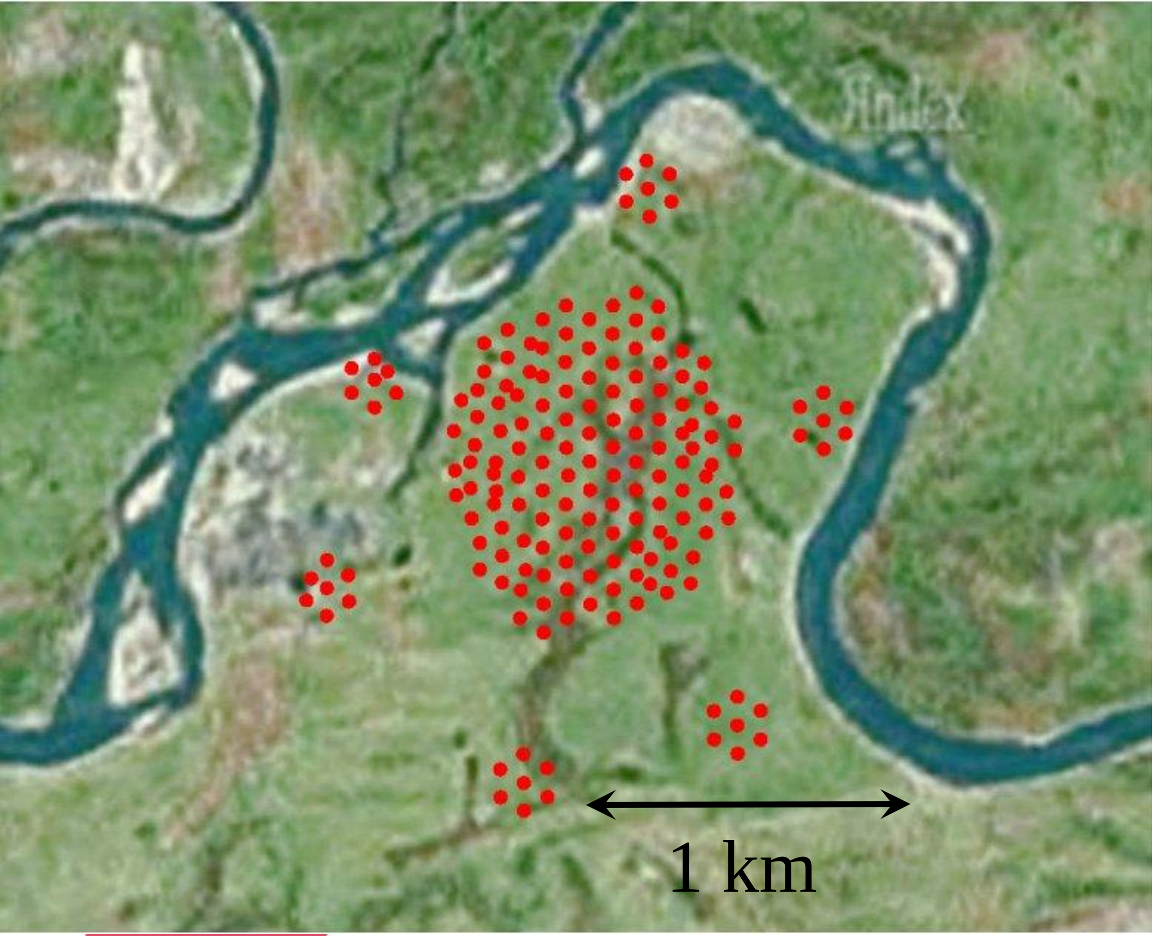
TUNKA & TAIGA

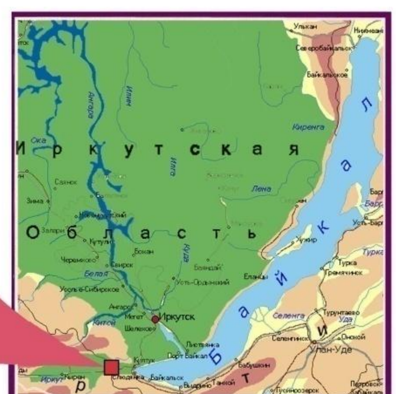
Vasily Prosin for the Tunka and TAIGA Collaborations

11.12.2018

Tunka-133



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



175 optical detectors
EMI 9350 and
HAMAMATSU Ø 20 cm

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

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

SINP MSU (Moscow)
API ISU (Irkutsk)
INR RAS (Moscow)
JINR (Dubna)
MEPHI (Moscow)
IZMIRAN (Moscow)
NSU (Novosibirsk)
BINR SB RAS (Novosibirsk)

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.).

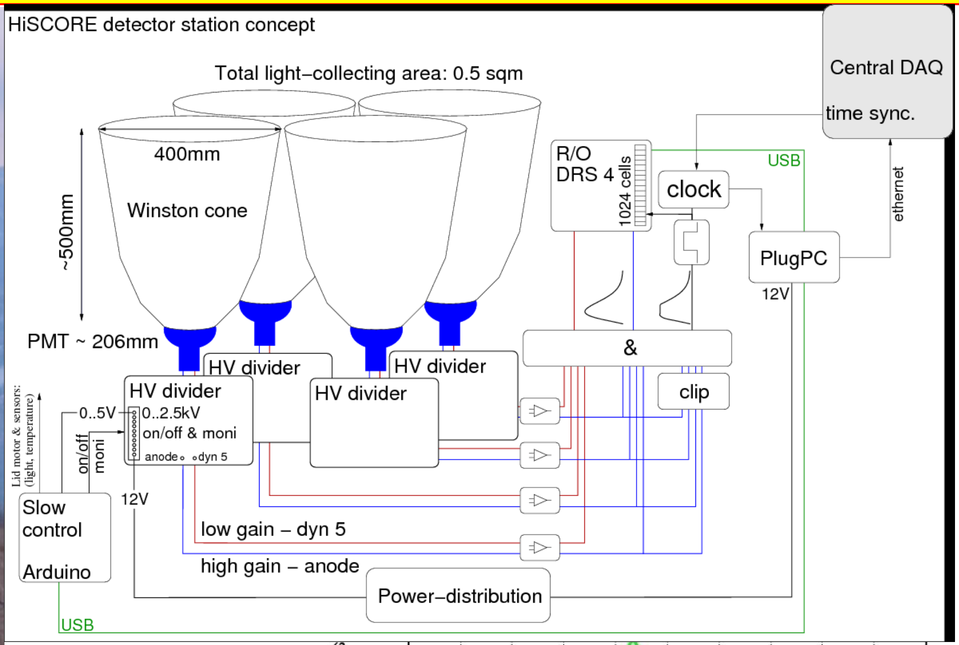
The TAIGA experiment - a hybrid detector for very High energy gamma-ray astronomy and cosmic ray physics in the Tunka valley

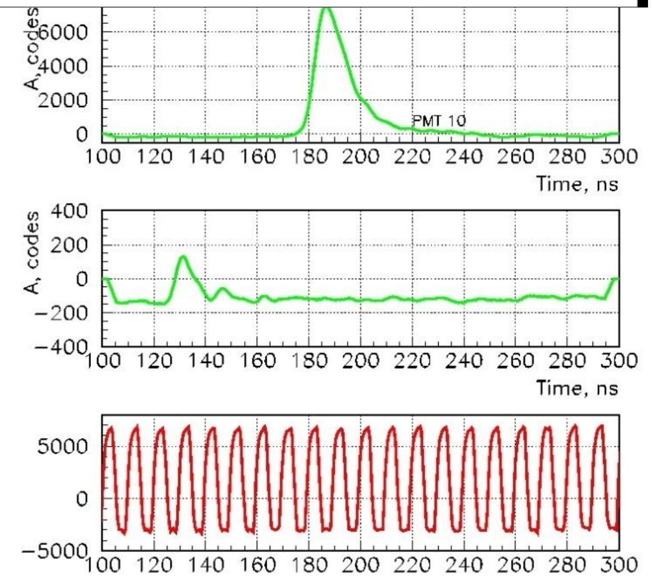
TAIGA = Tunka Advanced Instrument for cosmic rays and Gamma Astronomy

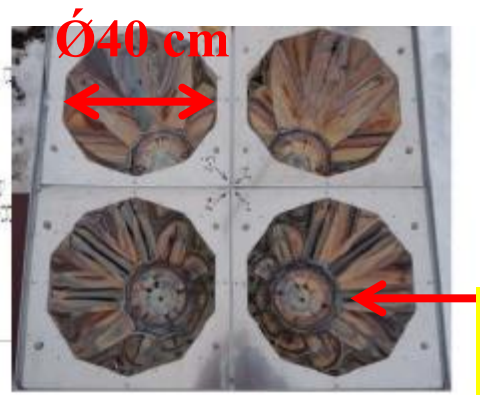
The main idea of large array of low threshold Air Cherenkov stations (the *non-imaging technique) with some Imaging Air Cherenkov Telescopes*.

The first stage of TAIGA – 1 km² array of 120 wide-angle timing stations for EAS parameters reconstruction and 3 IACTs. Commissioning will be at the end of 2019.

Low threshold wide angle station







Digitized with DRS-4.
Step = 0.5 ns
Synchronization and data taking via optical cable

Winston cone and PMT with 20 cm photocathode diameter

S tot = 0.5 m^2

TAIGA-IACT

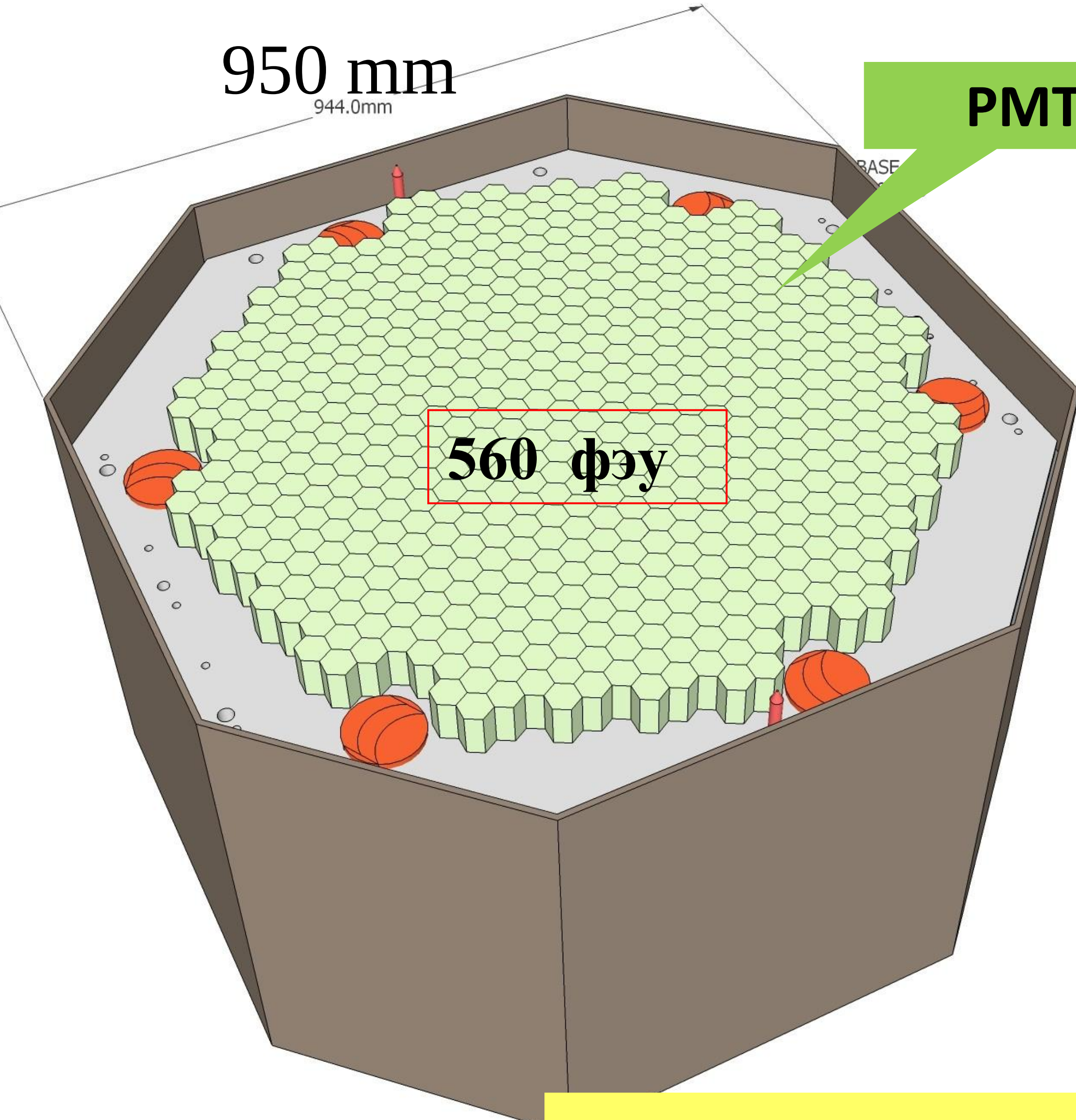
D = 4.32m   F = 4.75m

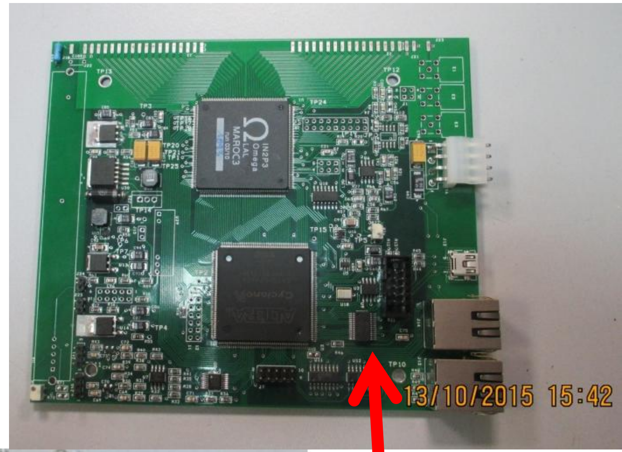
29 glass mirrors of 60 cm diameter

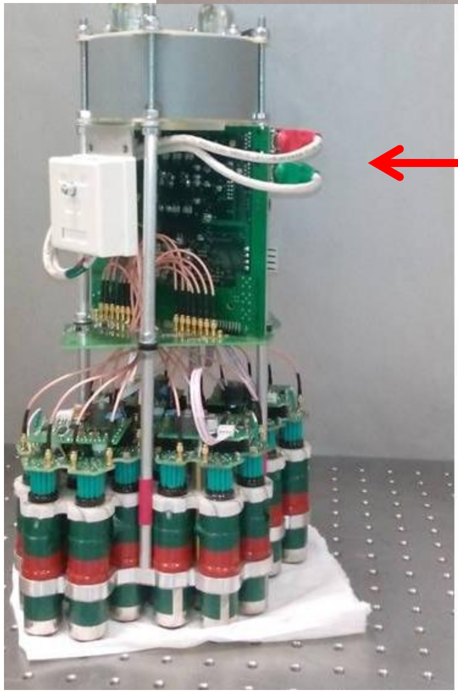
Camera : 560 PMTs (XP 1911) with 15 mm useful diameter of photocathode
Winston cone: 30 mm input size, 15 mm output size
aperture single pixel = 0.36°
FOV diameter ~ 9.6°

Energy threshold ~1.5 TeV

Camera of the TAIGA-IACT







Maroc-3
64 channel
board

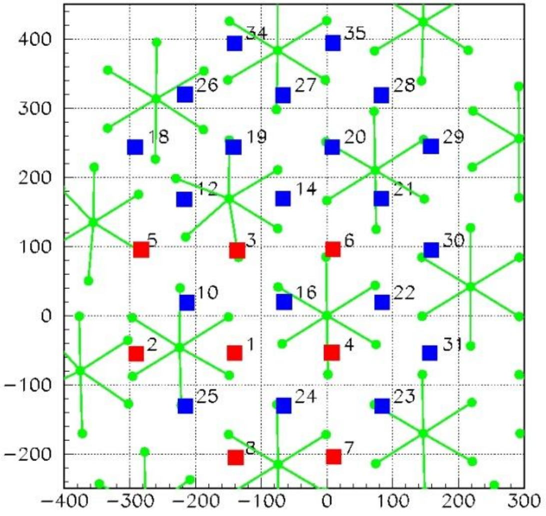
Cluster –
28 PMTs,
22 clusters
per camera

DAQ - MAROC3

HiSCORE

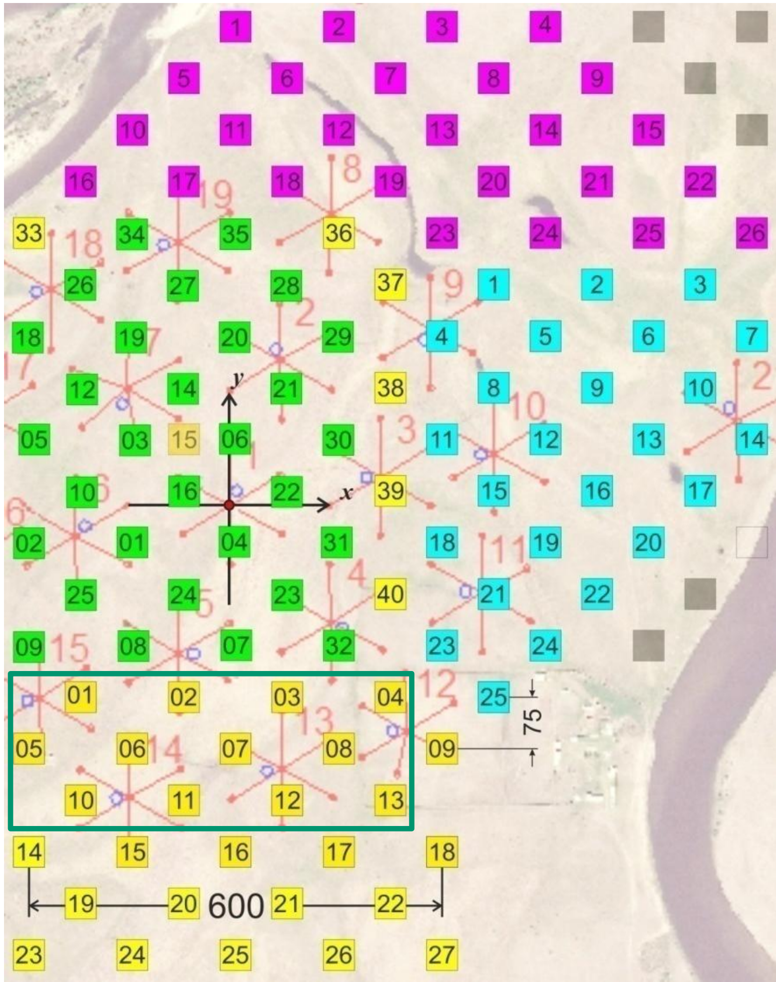
2014 – TAIGA-HiSCORE (High Sensitivity Cosmic Ray Explorer) – 9 stations

2016 – 2017
28 stations



2018
45 stations

Final plan –
120 stations



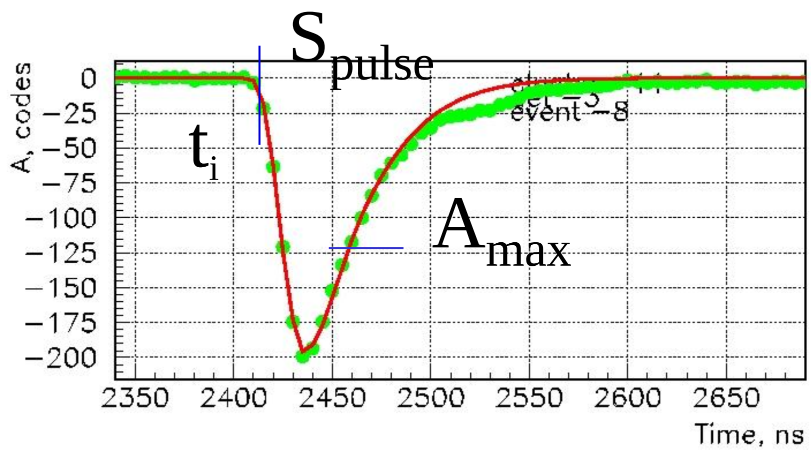
EAS Cherenkov Arrays Tunka-133 and TAIGA-HiSCORE Data Processing and Results

Tunka-133 single detector readout:

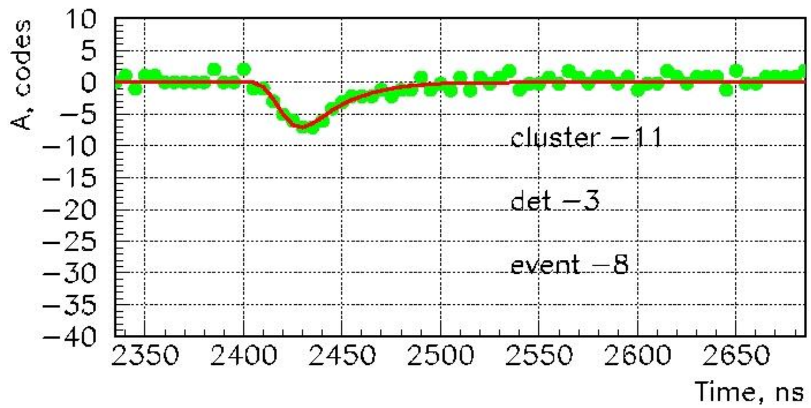
Fitting of the pulse and measuring of the parameters: $Q=c\cdot S_{pulse}$, A_{max}, t_i , $\tau_{eff}=S/A/1.24$

Time step = 5 ns

anode:



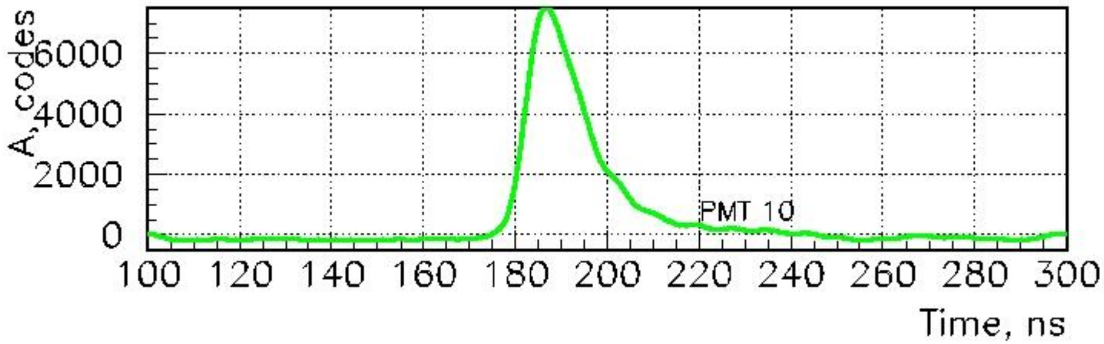
dynode:



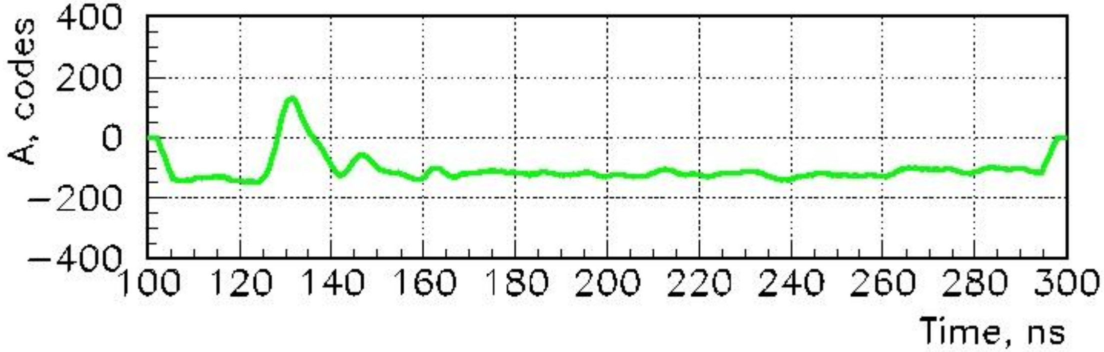
HiSCORE station sum record 2017-2018

Time step = 0.5 ns

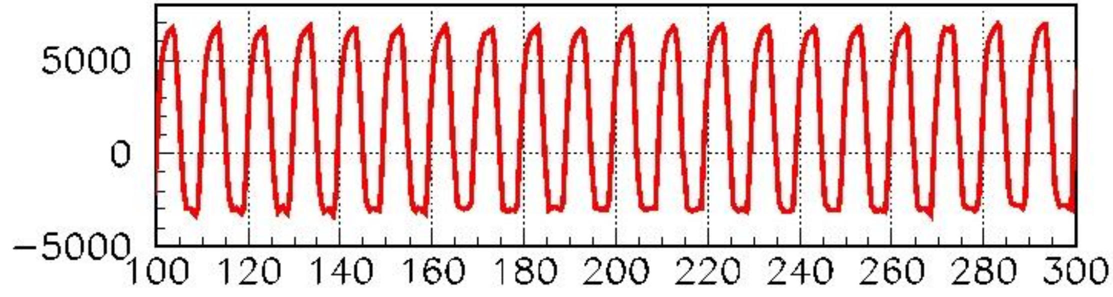
anode:



dynode:

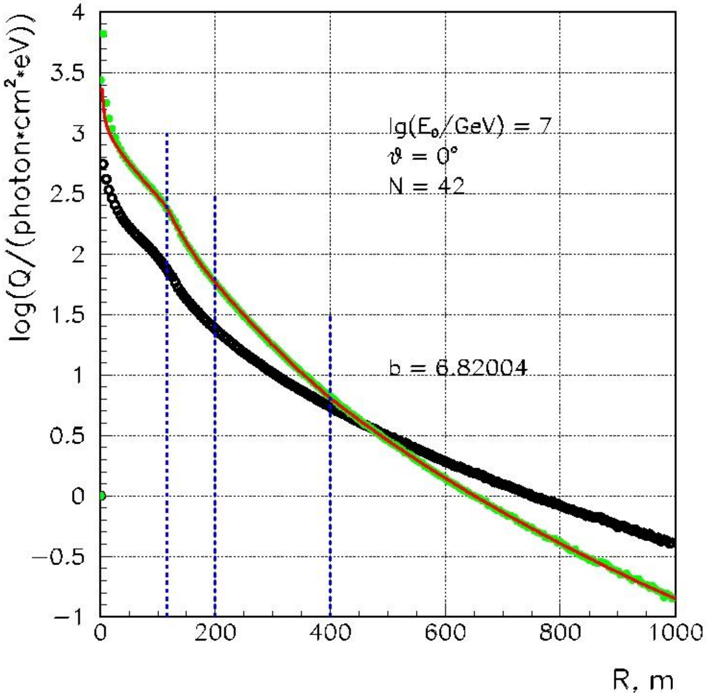


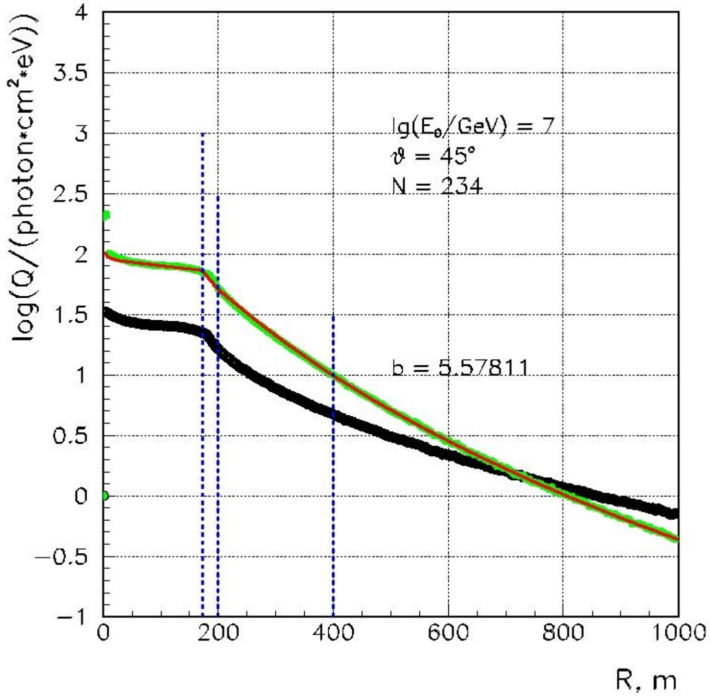
synchronisation 100 MHz:



EAS parameters reconstruction

CORSIKA: Fitting functions – LDF and ADF



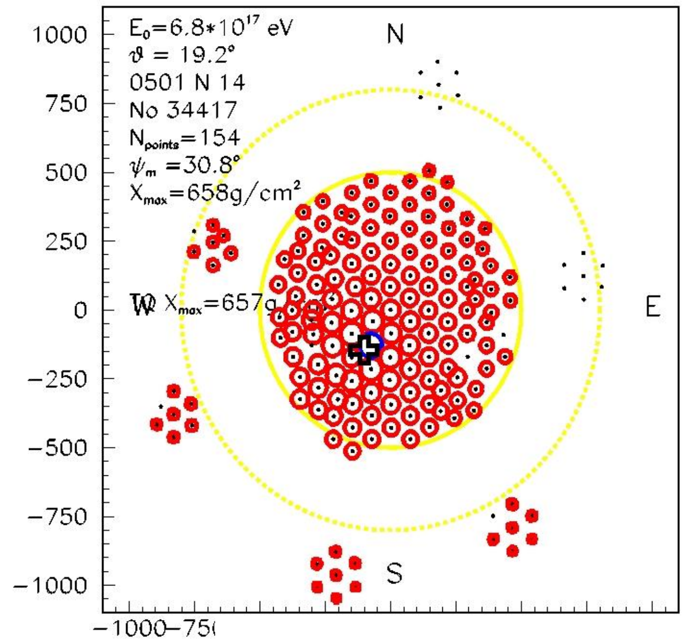


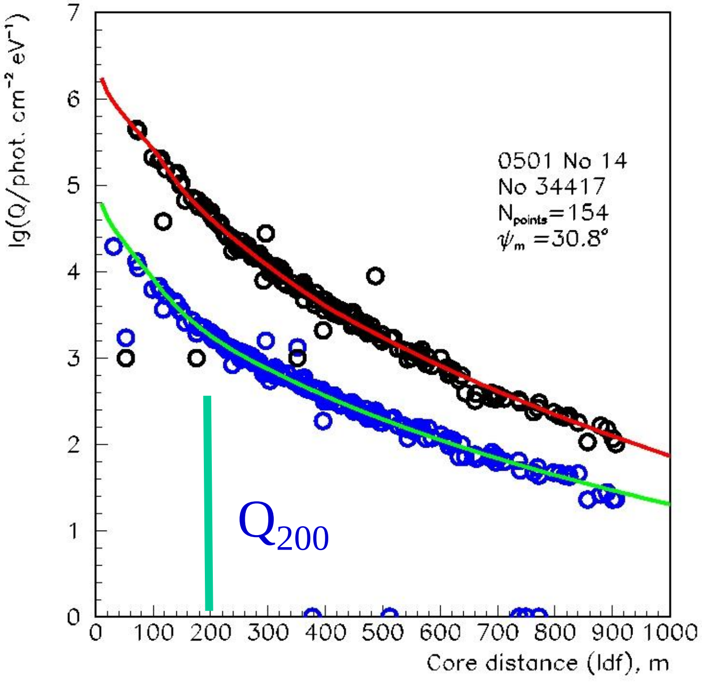
ADF: **$A(R) = A(400)\cdot((R/400+1)/2)^{-bA}$ steepness**: **b_A**

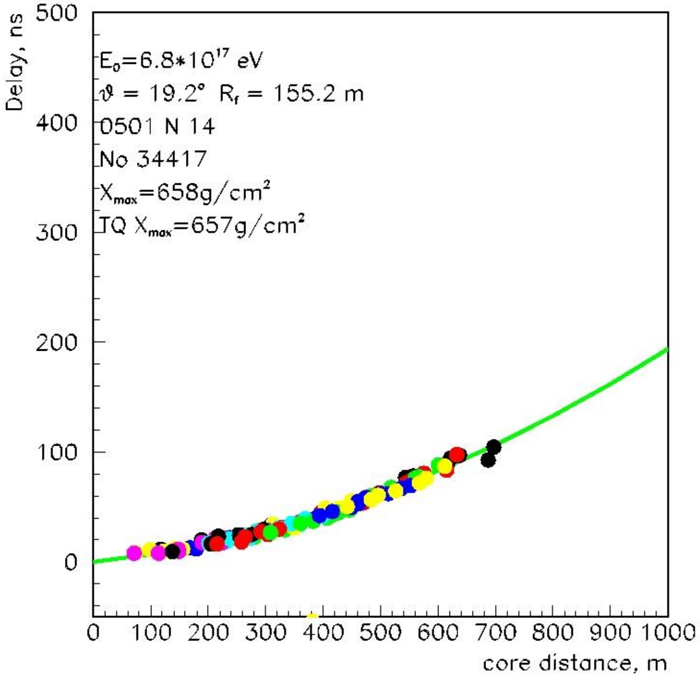
LDF: **$Q(R) = Q(300)\cdot((R/300+1)/2)^{-bQ}$** steepness: **$b_Q$**

$b_A > b_Q$

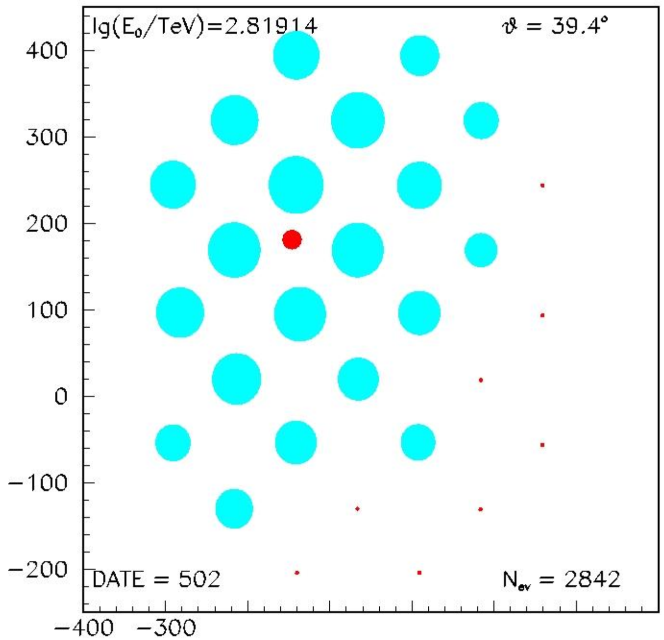
An Example of Tunka-133 event reconstruction

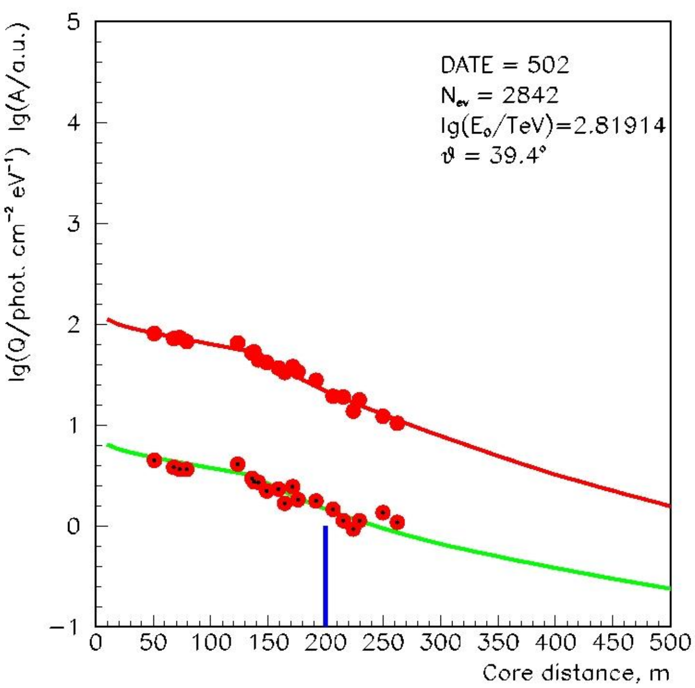


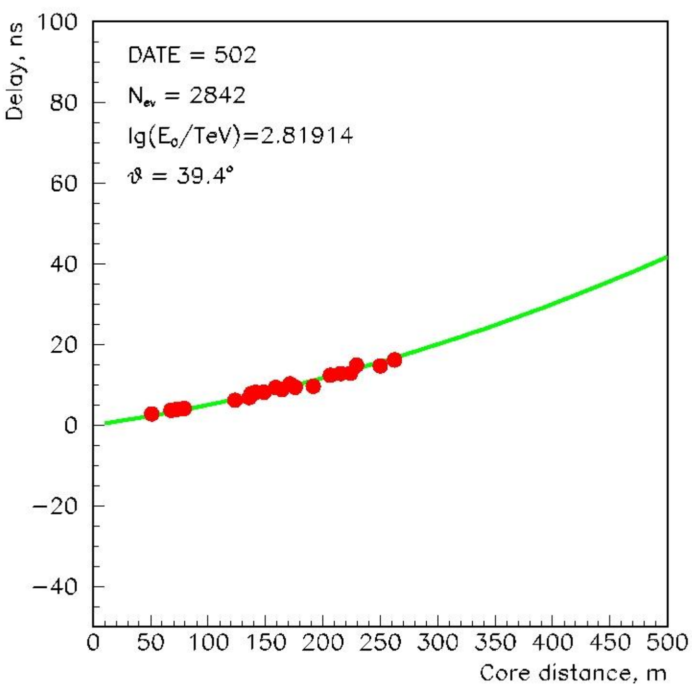




An Example of TAIGA-HiSCORE event reconstruction



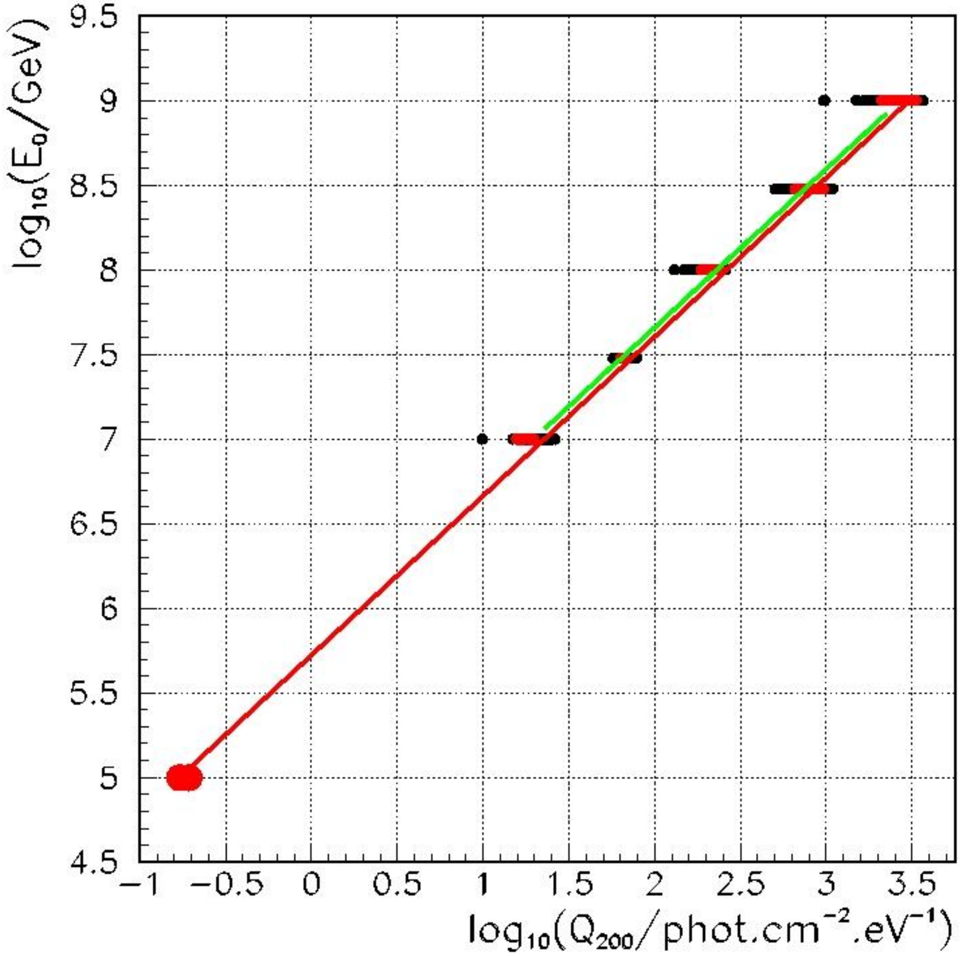




EAS paramerters reconstruction by Cherenkov light flux density Q_{200}

Fitting of pulse amplitudes (A_i) with ADF.
Getting of X_0, Y_0 and ADF steepness (b_A).
Getting Q_{200} with LDF

$$E_0 = C \cdot Q_{200}^{0.94}$$



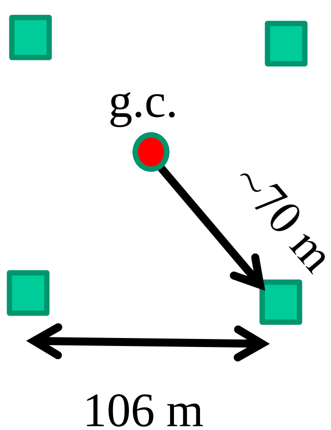
EAS parameters reconstruction by Q_{70}

For energy $E_0 < 10^{15}$ eV:

X_0, Y_0 is the gravity center of A_i for 4 stations, closest to the core.

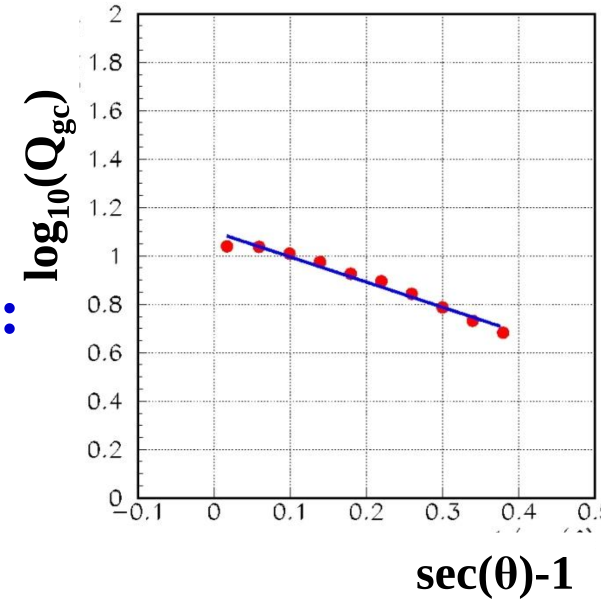
Q_{gc} is mean value by these 4 stations

Minimal event configuration:

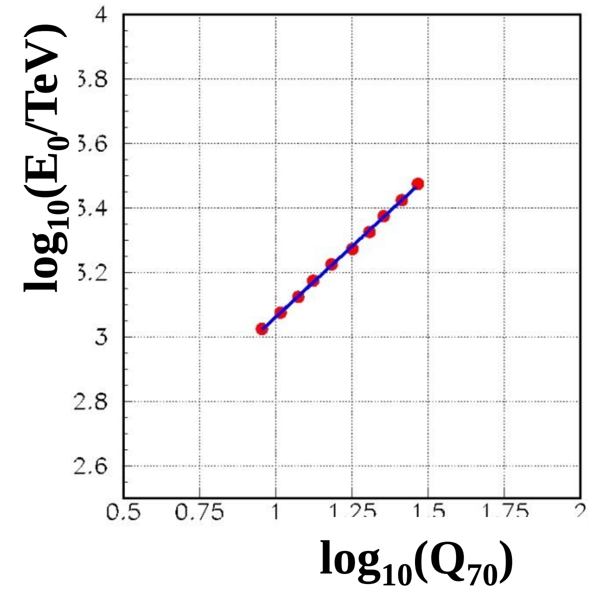


Experimental correlations are obtained for the energy range $10^{15} - 3 \cdot 10^{15}$ eV :

$$Q_{70} = Q_{gc} \cdot 1.06(\sec(\theta)-1) :$$

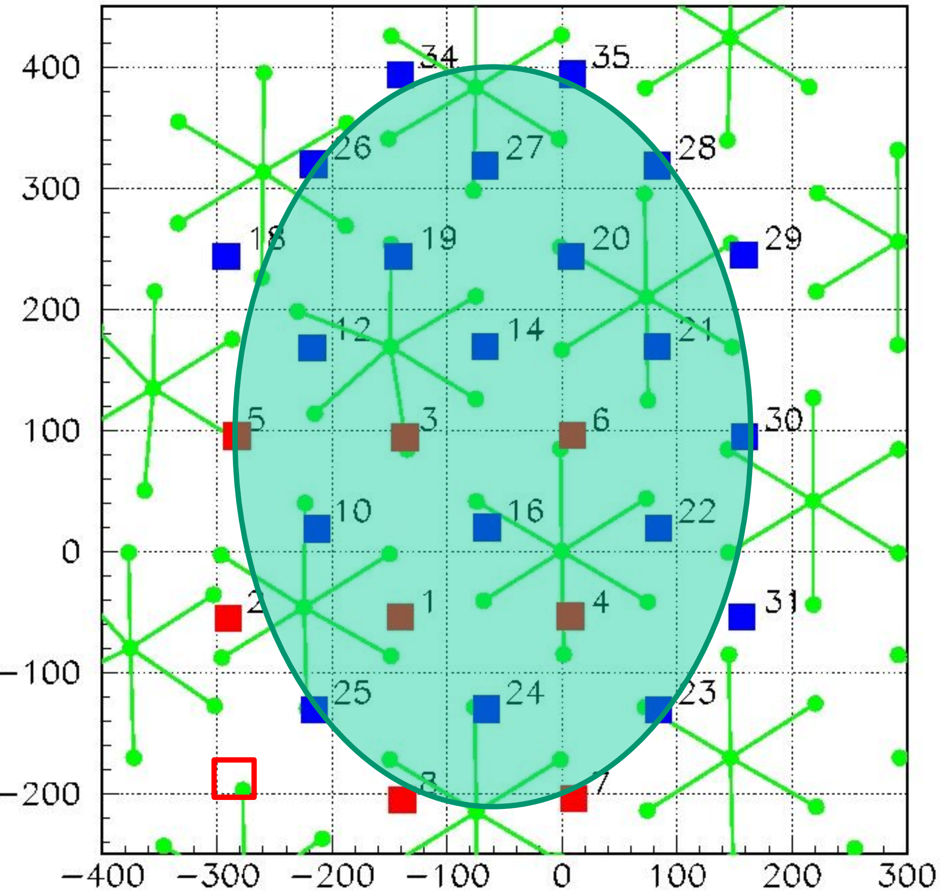


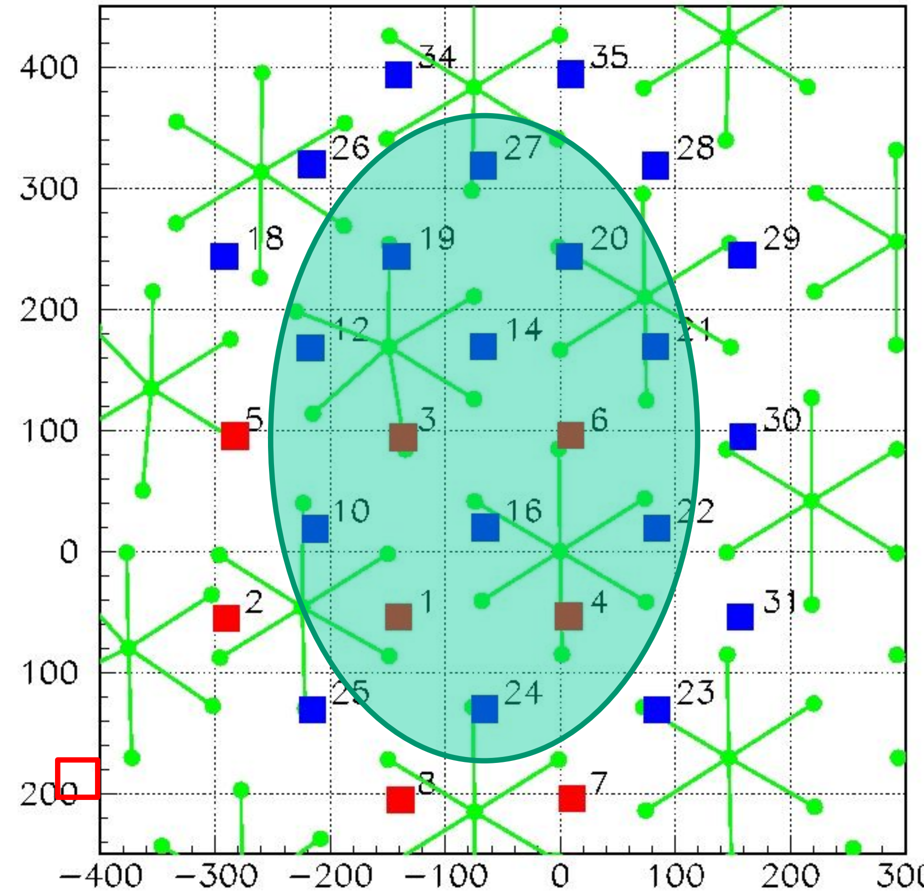
$$E_0 = C \cdot Q_{70}^{0.88} :$$



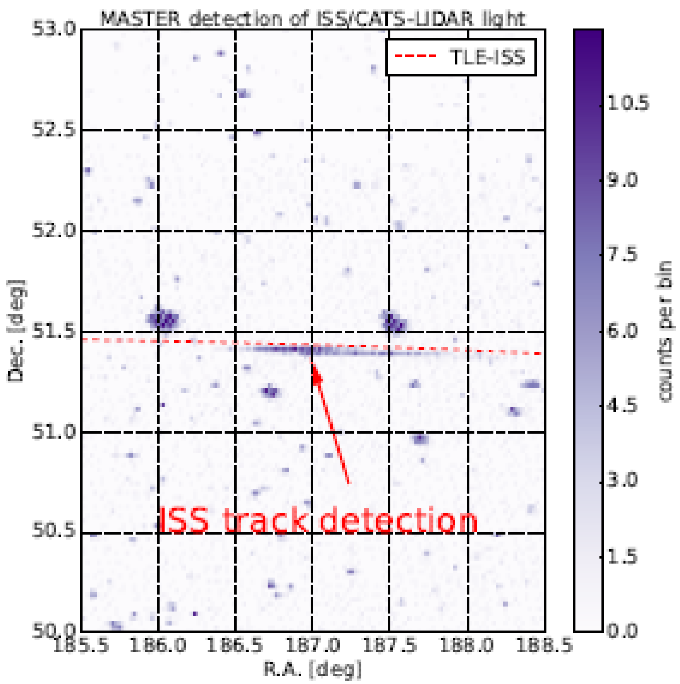
HiSCORE Effective Area

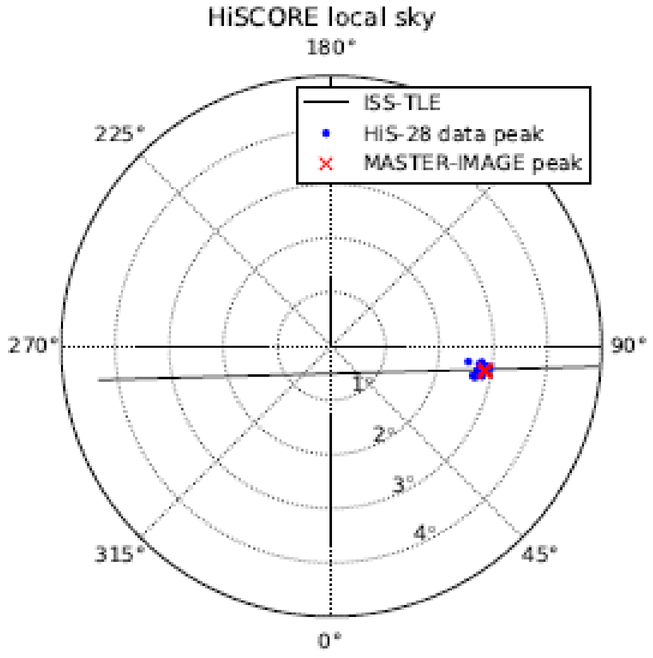
fitted events $E_0 > 10^{15}$ eV **gravity center events $E_0 < 10^{15}$ eV**





Common observation of ISS LIDAR by HiSCORE and optical telescope MASTER





Absolute pointing of HiSCORE   Δψ ~ 0.1°

EXPERIMENTAL DATA

Tunka-133:
7 seasons, 350 nights, 2175 h, ~$1.5 \cdot 10^7$ single cluster events
> 95% effective registration:
~375,000 events with $E_0 > 6 \cdot 10^{15}$ eV,
~4,200 events with $E_0 > 10^{17}$ eV

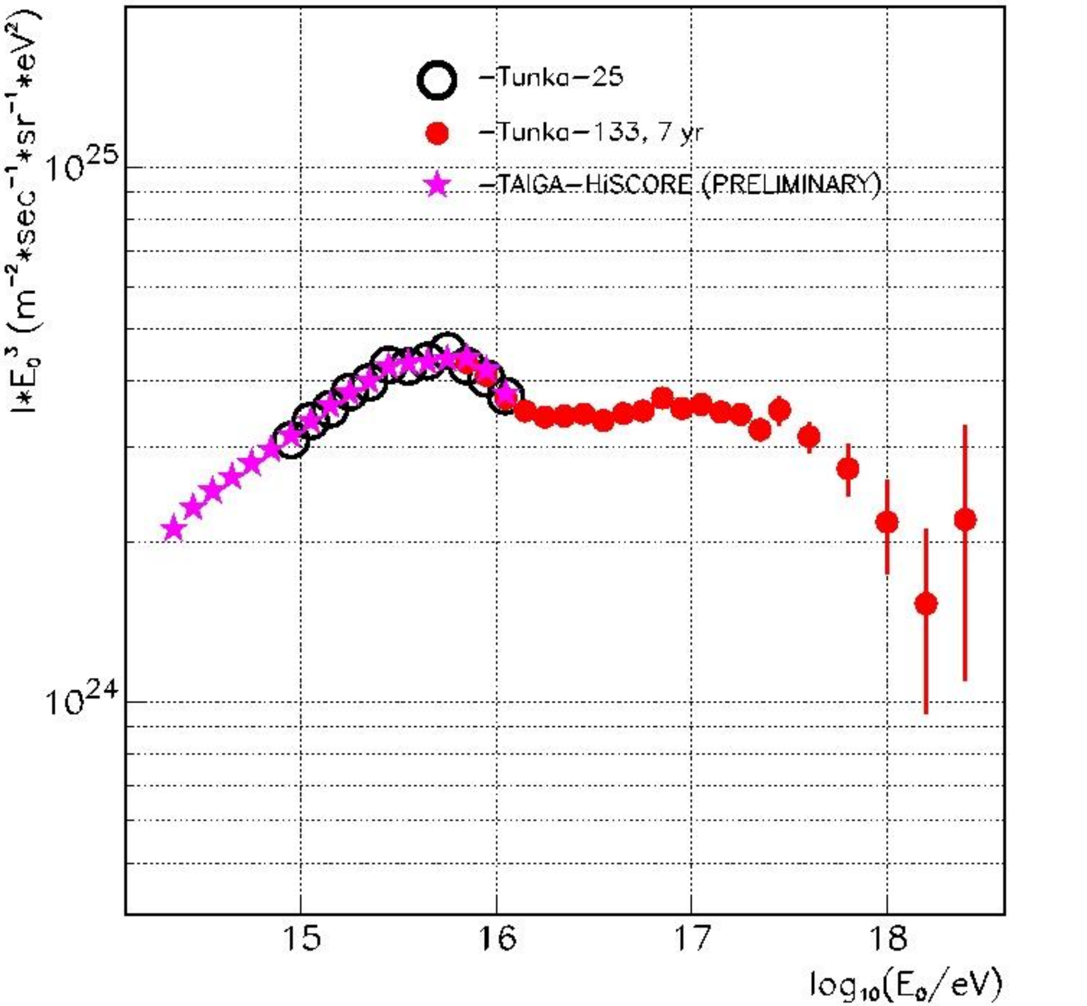
TAIGA-HiSCORE:
season 2017-2018, 35 nights, 180 h, ~$3 \cdot 10^8$ single station events
> 95% effective registration:

$2 \cdot 10^{14} – 3 \cdot 10^{14}$	~29,000 (one night 28.10.2018, Q_{70})
$3 \cdot 10^{14} – 10^{15}$	~700,000 (35 nights, Q_{70})
$10^{15} – 10^{17}$	~170,000 (35 nights, Q_{200})

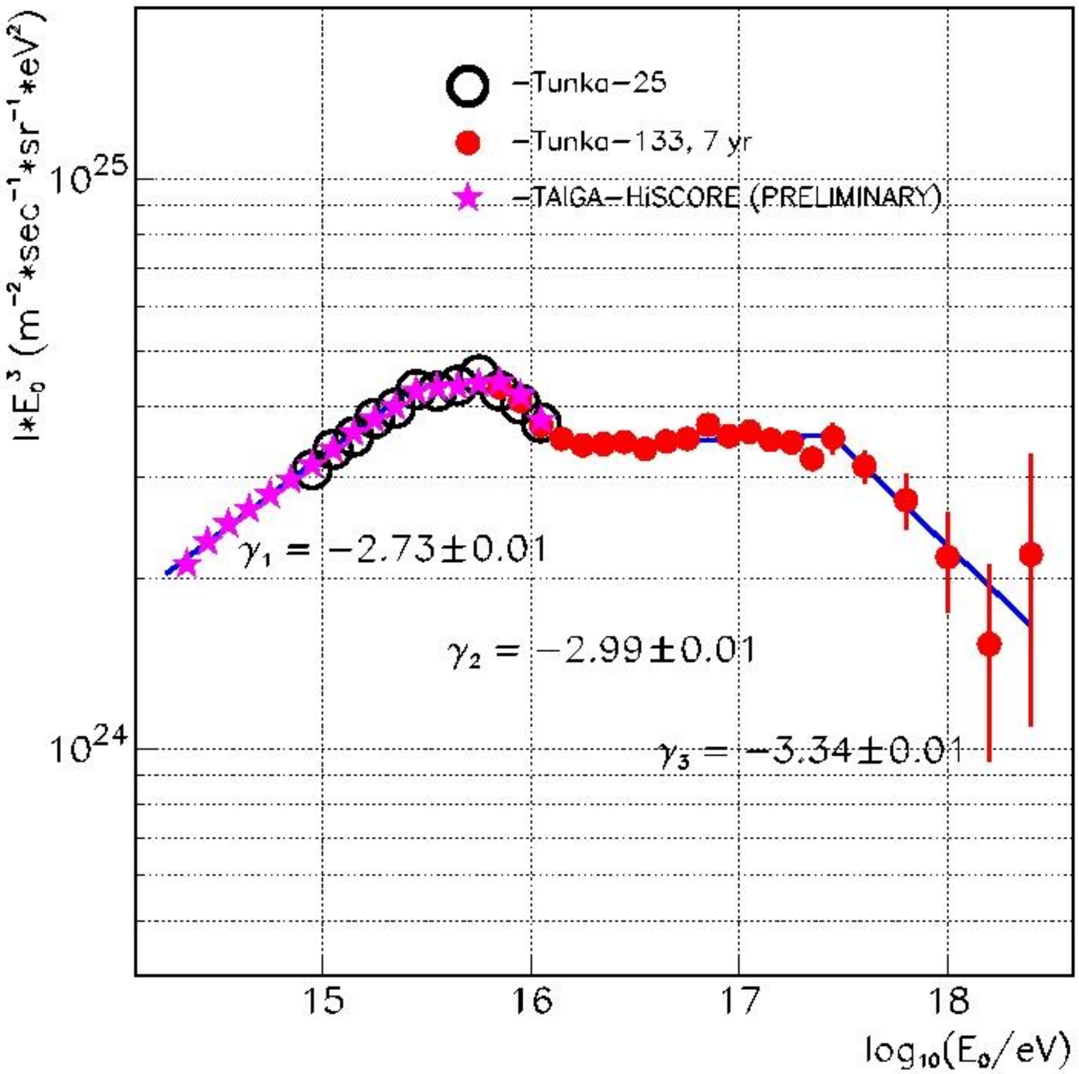
Tunka Primary Energy Spectra with EAS Cerenkov Light

Tunka-133:
350 clean moonless nights
2175 h
~375,000 events
With ~100% efficiency
~4200 events with $E_0>10^{17}$ eV

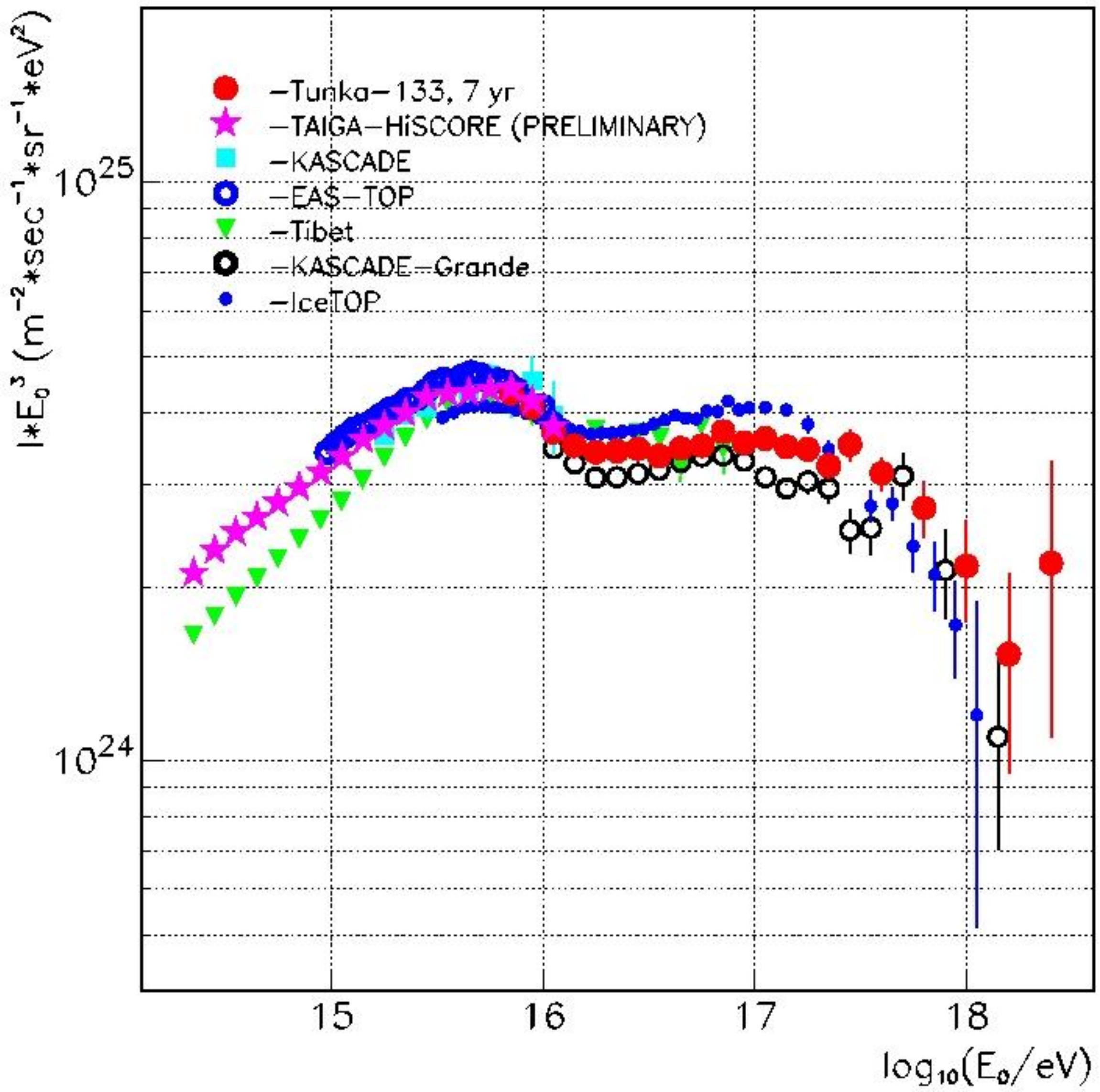
TAIGA-HiSCORE:
35 clean moonless nights
180 h
~900,000 events
with ~100% efficiency



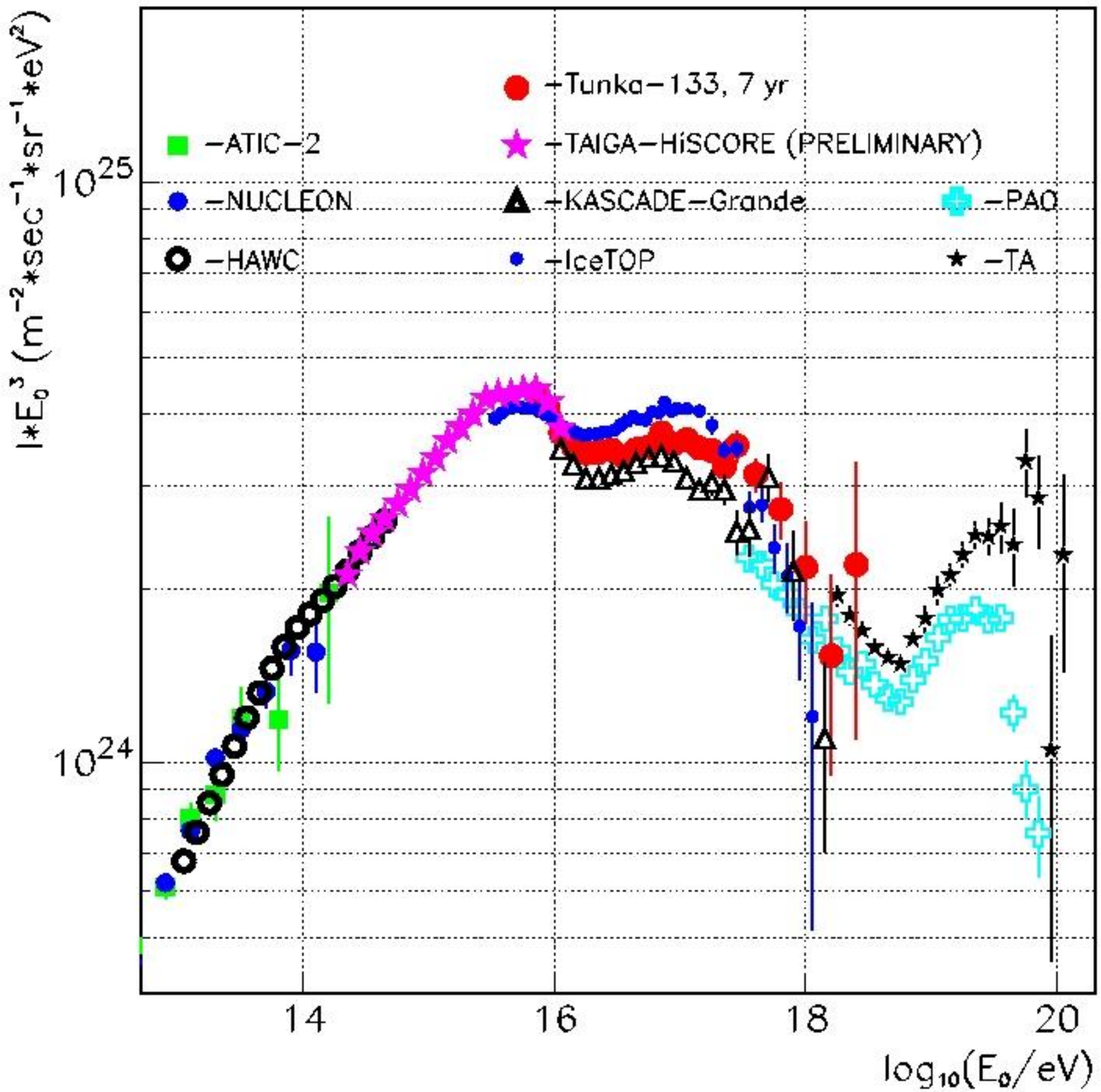
Energy spectrum: power law fitting



Energy spectrum comparison with intermediate energy experiments



United Primary Energy Spectrum $10^{13} - 10^{20}$ eV



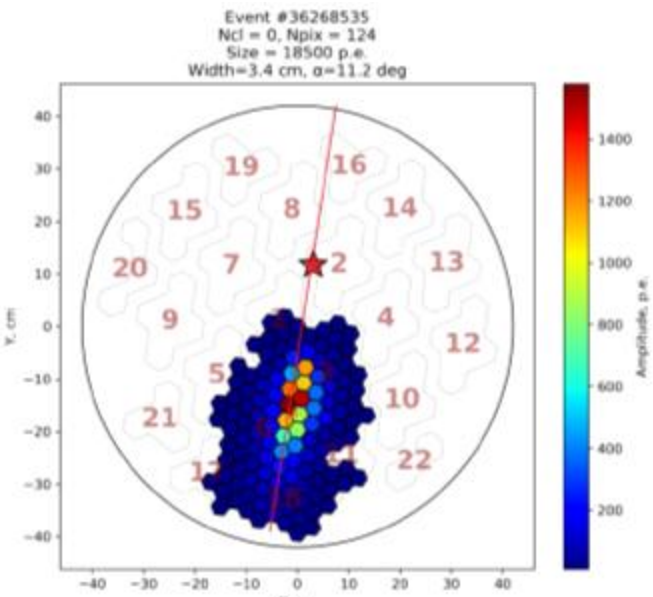
Perspectives of Mass Composition Study

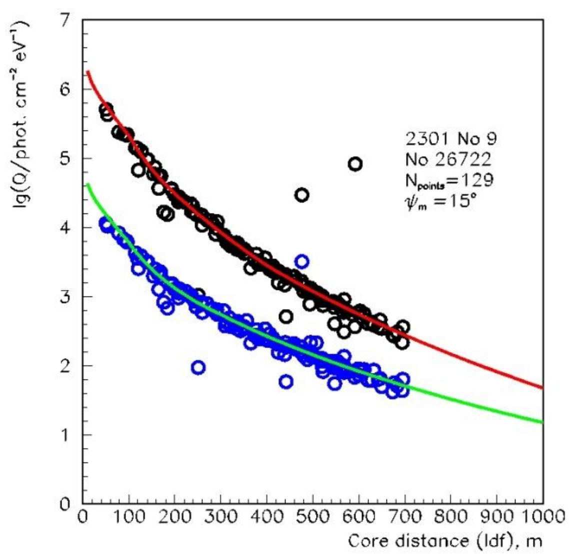
$10^{14} – 10^{15}$ eV
IACT image analysis similar to Argo experiment

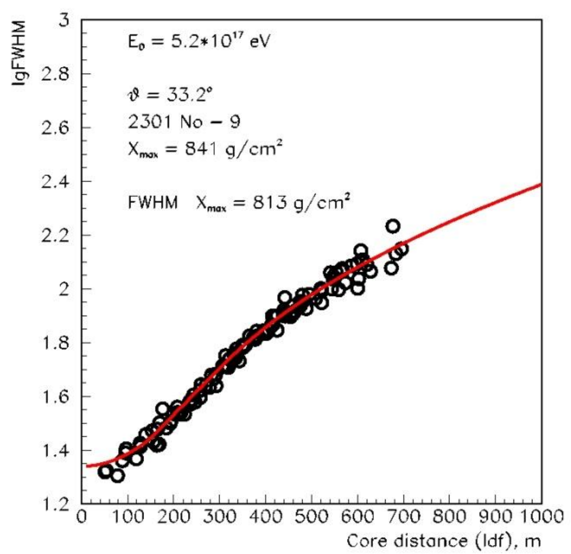
$10^{15} – 10^{18}$ eV

Cerenkov light ADF steepness b_A

Cerenkov light pulse width at R_{core}= 300 – 400 m



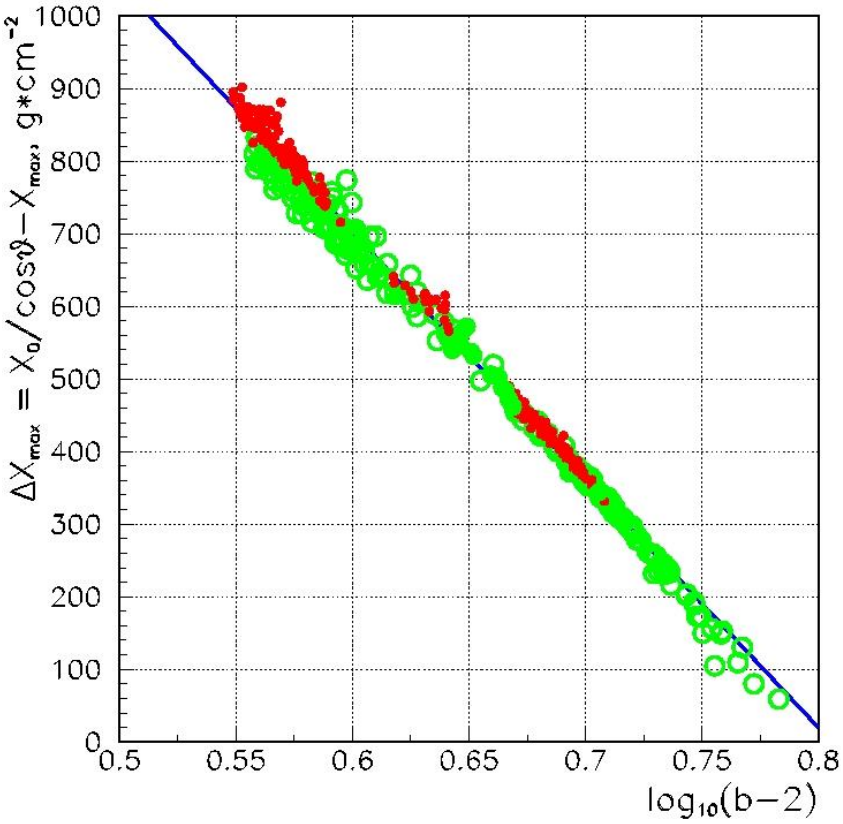




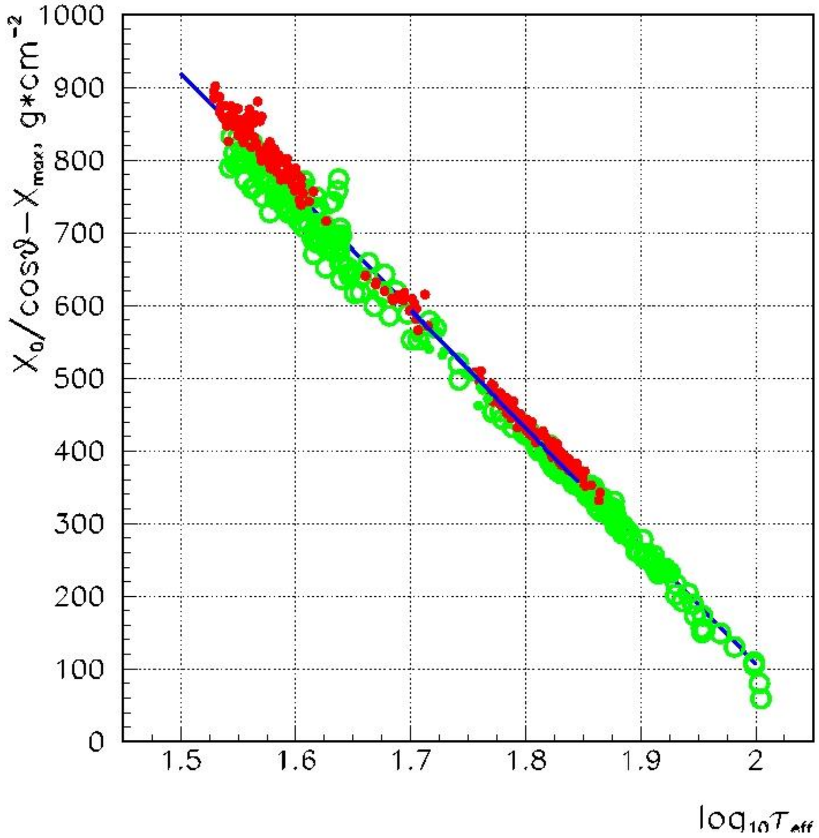
CORSIKA

(Correlations are model, energy, zenith angle and composition independent)

ΔX_{max} vs. b_A (ADF steepness)



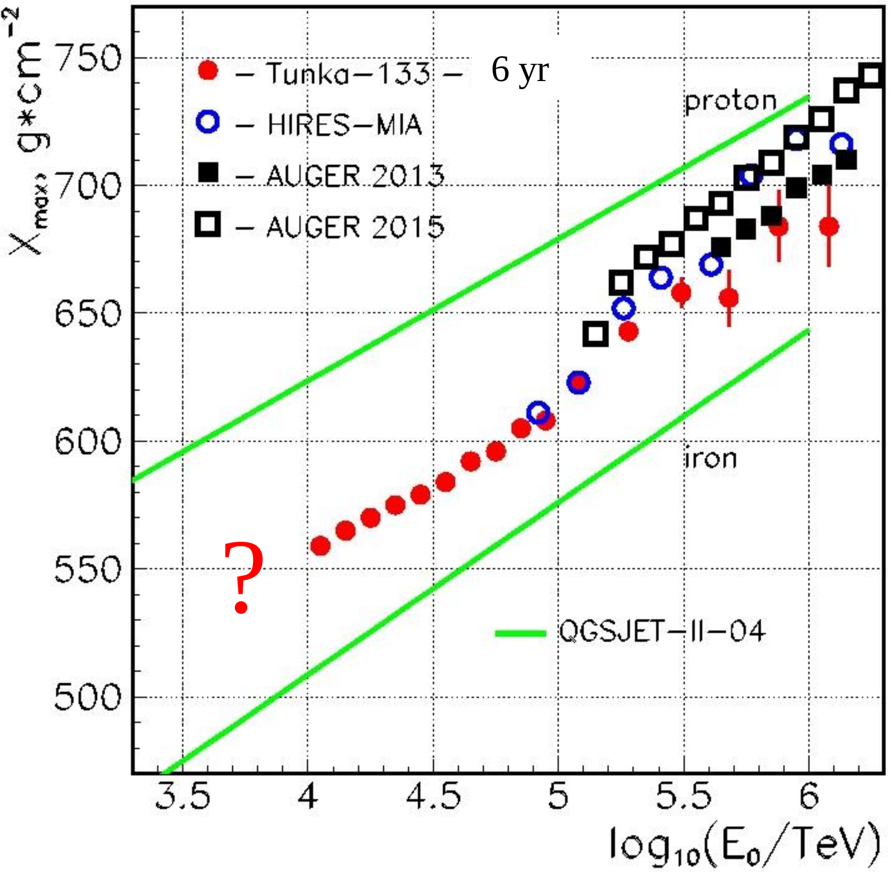
ΔX_{max} vs. $\tau_{eff}(400)$

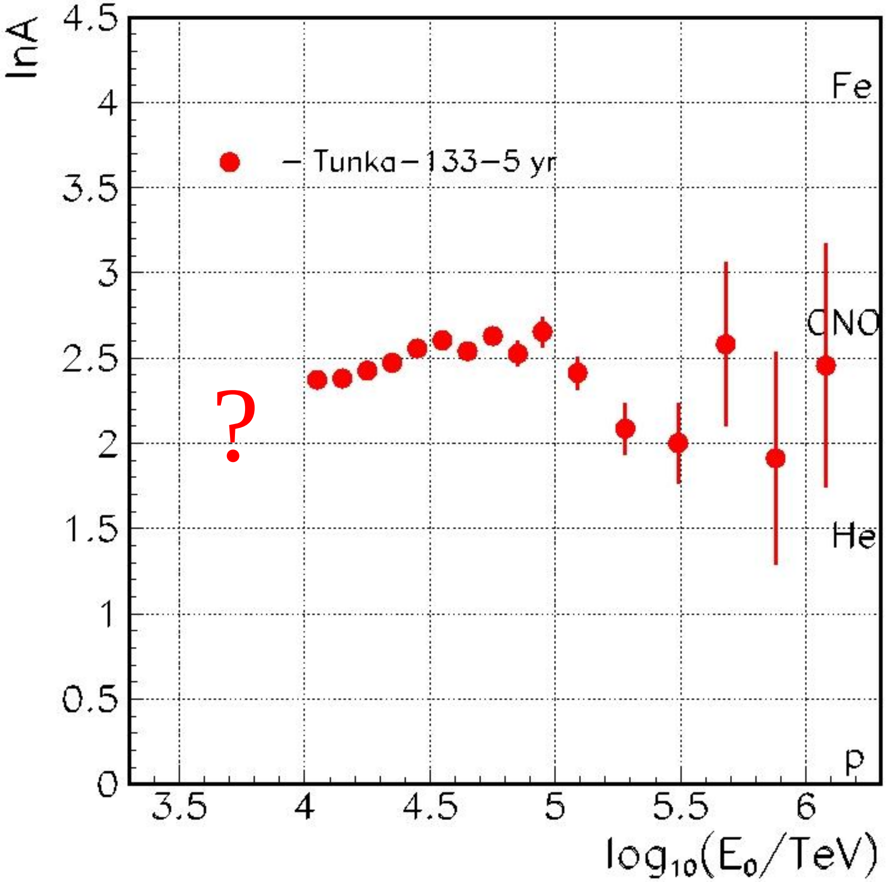


~ 500 events – 10^7 GeV < E_0 < 10^8 GeV, θ = 0°, 30°, 45°

green – p, red – Fe

$\langle X_{max} \rangle$ vs. E_0
Tunka-133 results of 2017





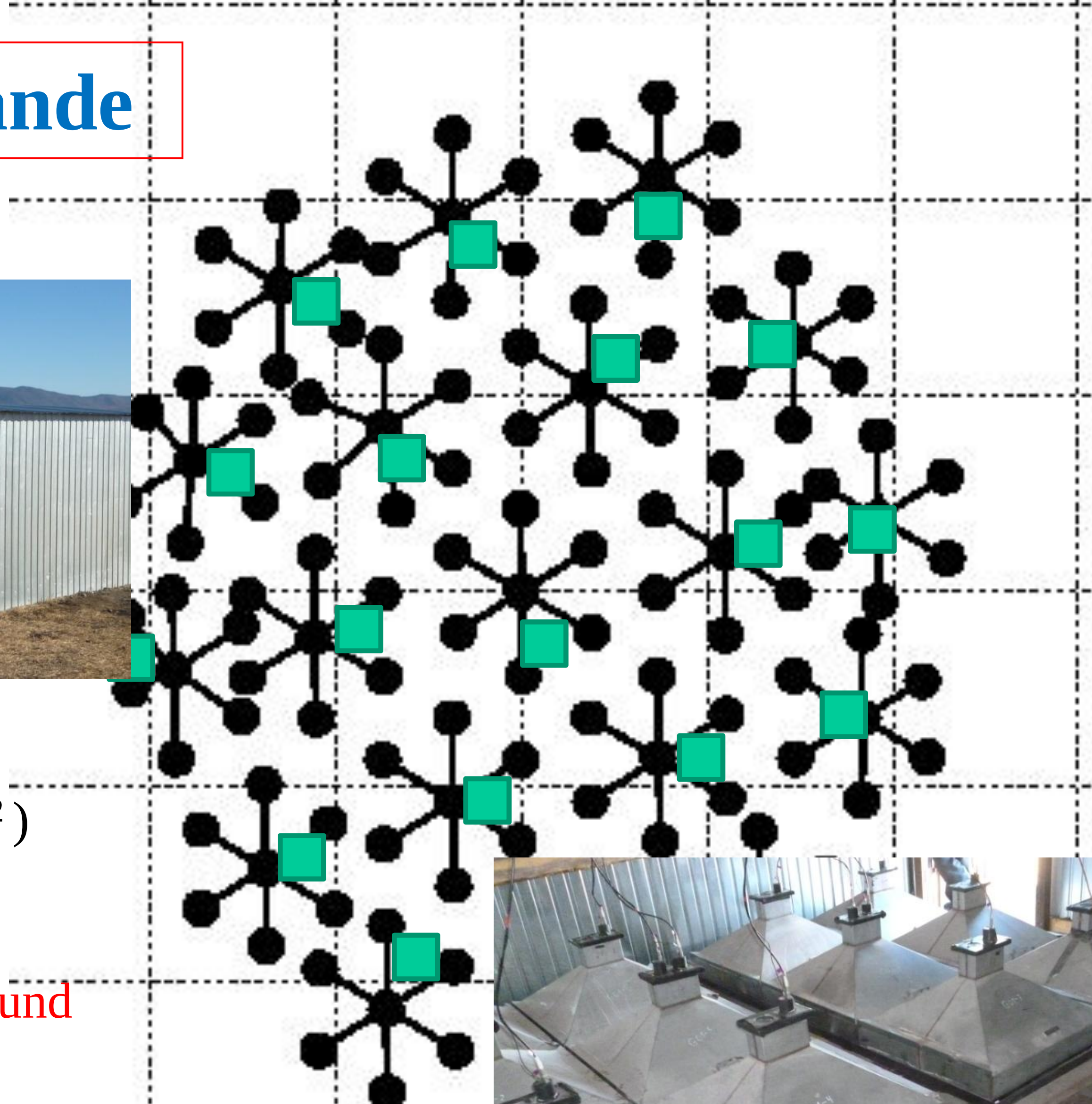
? – because of the works: ATIC-2, ARGO, HAWC

The new analysis of the TAIGA-HiSCORE data is needed.

The new CORSIKA simulations are in progress now.

Tunka-Grande

19 stations



228 detectors (0.64 m^2)
 on the surface

152 detectors undeground
(muons detectors),
total area = 100 m^2

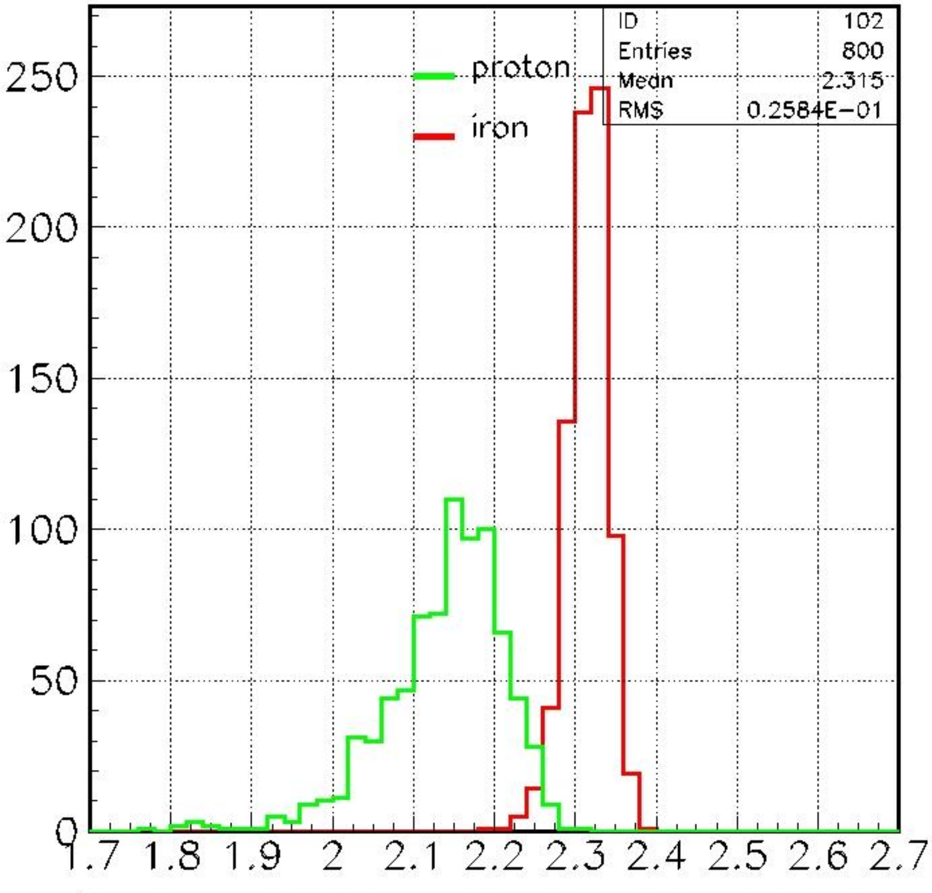
Perspectives of Mass Composition Study

Tunka-Grande data
for the energy range $10^{17} – 10^{18}$ eV
Composition sensitive parameter:

$$S = \log_{10}(\rho_\mu(200)) – C\cdot \log_{10}(\rho_{sc}(200))$$

ρ_μ muon density
ρ_{sc} all particle density

C ~ 0.9



S – distribution

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:

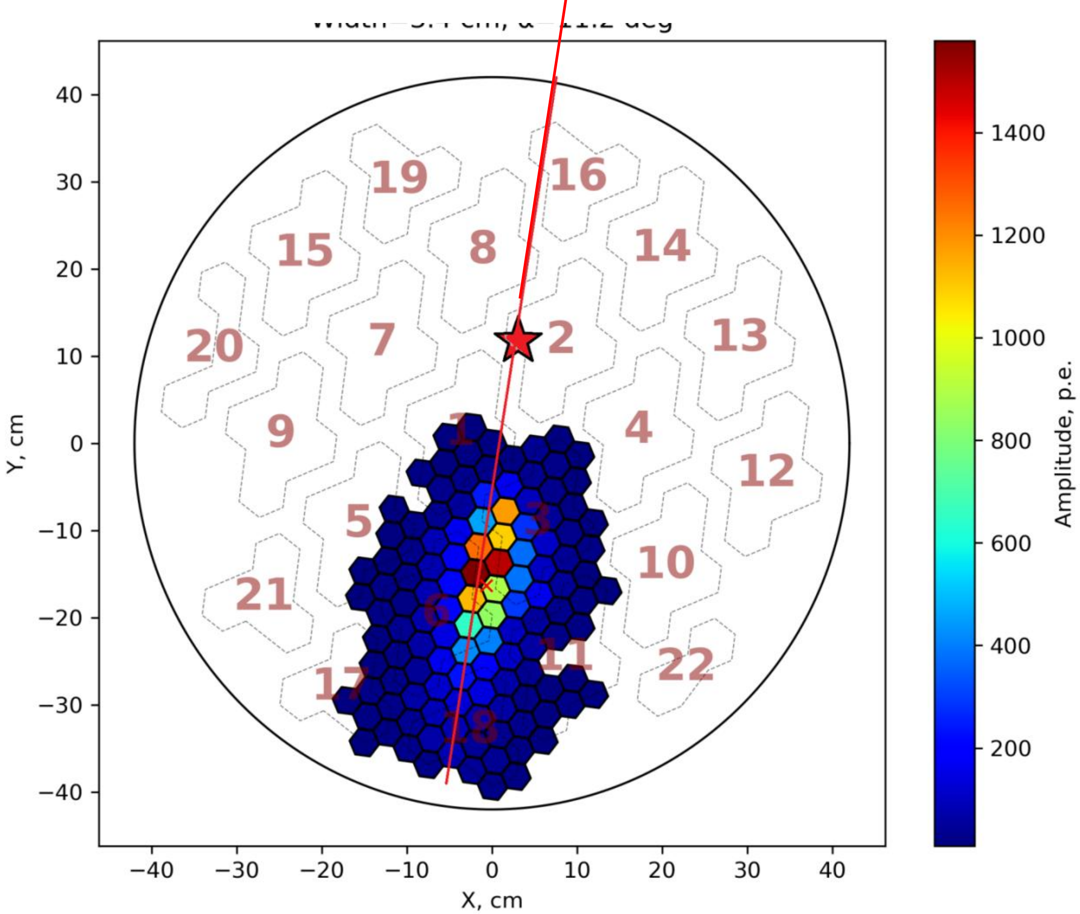
Crab - 130 hr
Mrk-421 - 120 hr
Tycho - 190 hr

-
- 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.

IACT and HiSCORE joint events

EAS core position
from HiSCORE



"Hadron –like" event

Energy from HiSCORE:
840 TeV

Gamma-like events

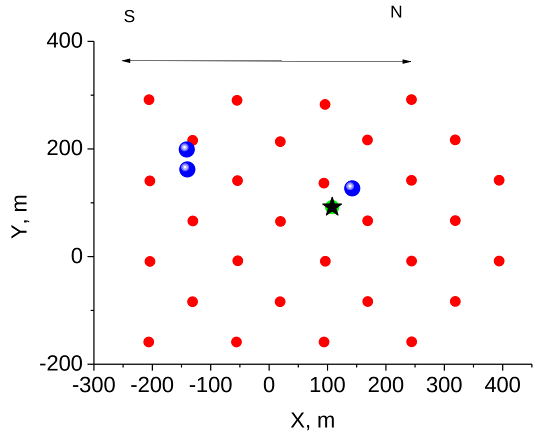
Ψ – the angle between the telescope direction to the Crab and the shower direction by HiSCORE)

Effective Time – 25 hours

Full number of events with ψ <1° 255 events

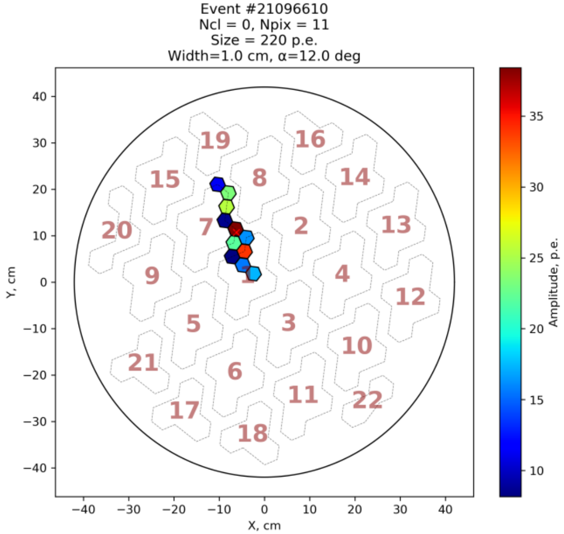
Criteria for Hillas parameters:

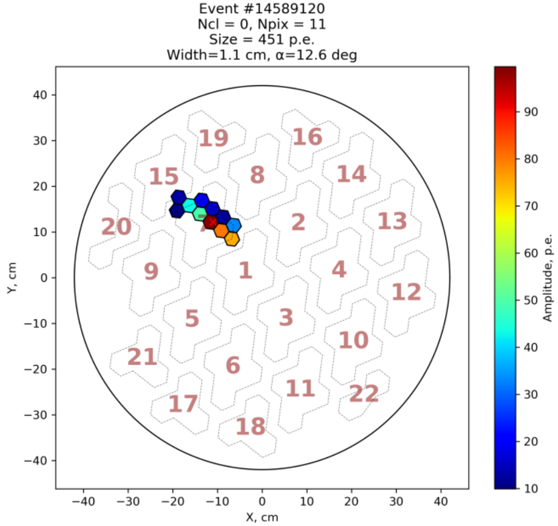
width < 0.16, alfa < 18° 7 events

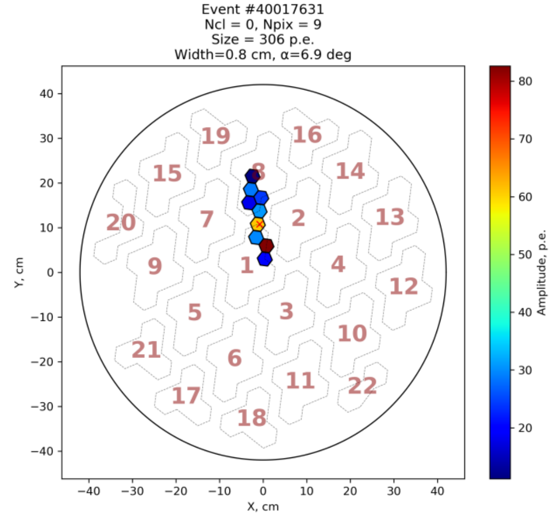


Gamma energy ~ 50 - 60 TeV

Distances ~ 50 m, 299 m, 270 m



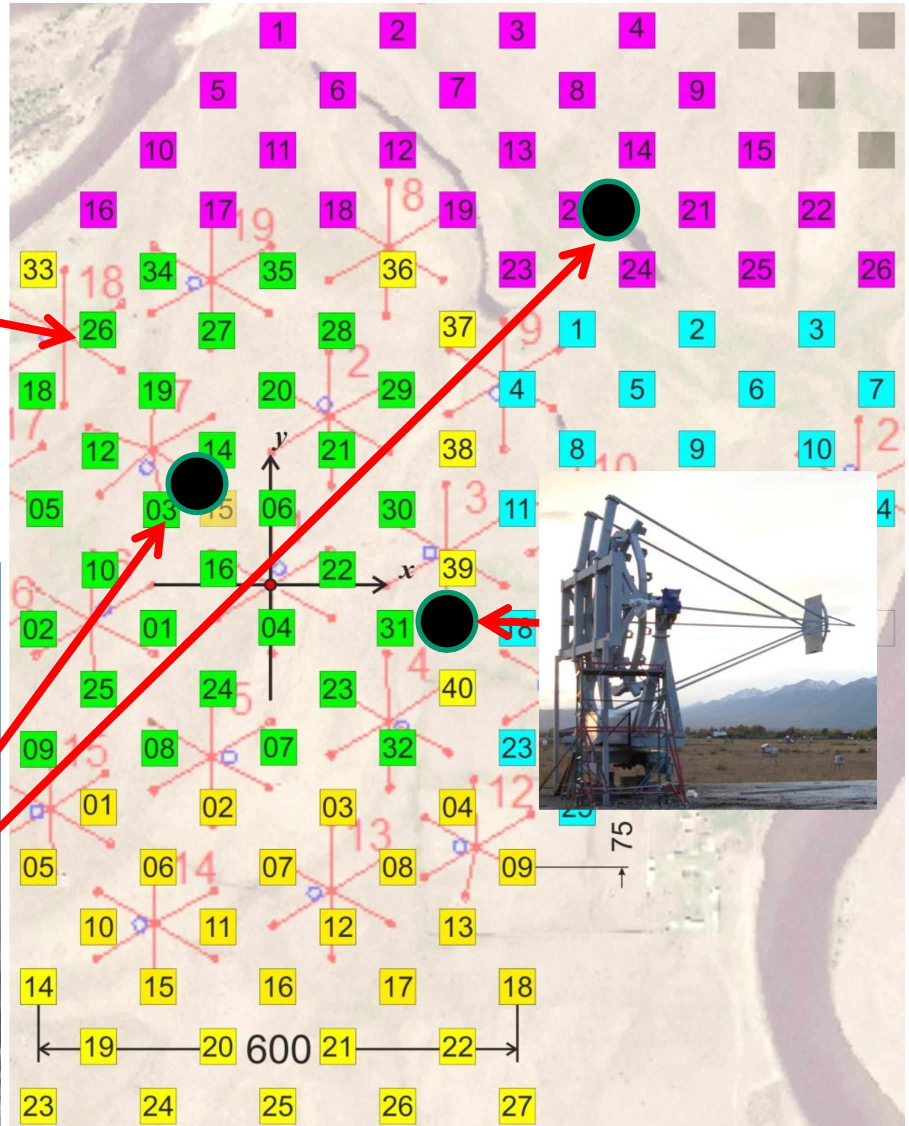




Expected number with energy Eg>50 TeV ~ 5-10 events

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 are planned to be installed next year (2019)

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.**

Conclusions

1. United primary energy spectrum, obtained by the same method of EAS Chernkov light flux measurement cover 4 orders of magnitude and let us confirm that the primary energy measurements are in good agreement from relatively low (10^{14} eV) to extremely high energy (10^{20} eV)
2. Deployment of the full scale TAIGA prototype – 120 wide-angle stations and three IACTs is planned for 2019.
3. The results from joint operation of HiSCORE and IACT we hope will let us estimate the primary mass composition for the energy around 10^{15} eV.

Thank you!

Tunka-REX

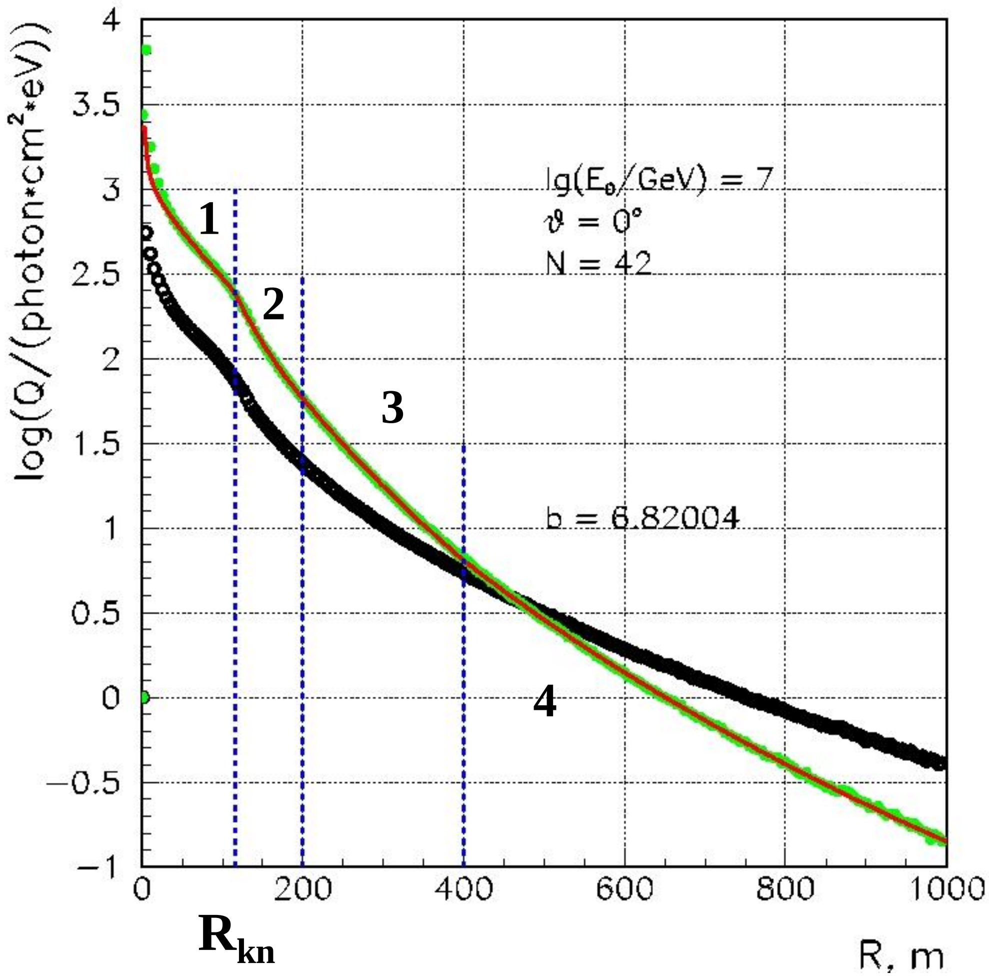
Connection of 2 antennas to
2 free channels of FADC

38 antennas are situated at the area of 1 km^2 now.

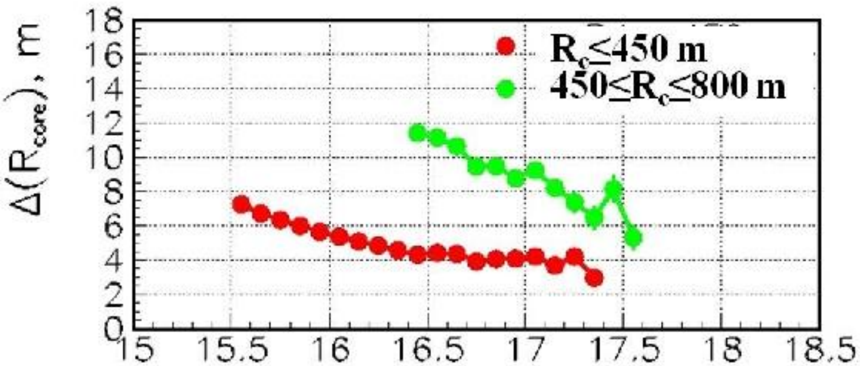
ADF:

1. $A(R) = A_{kn} \cdot \exp((R_{kn}-R) \cdot (1+3/(R+2))/R_0)$
2. $A(R) = A_{kn} \cdot (R_{kn}/R)^{c}$
3. $A(R) = A(400) \cdot ((R/400+a)/(a+1))^{-b}$
4. $A(R) = A(400) \cdot ((R/400+1)/2)^{-b}$

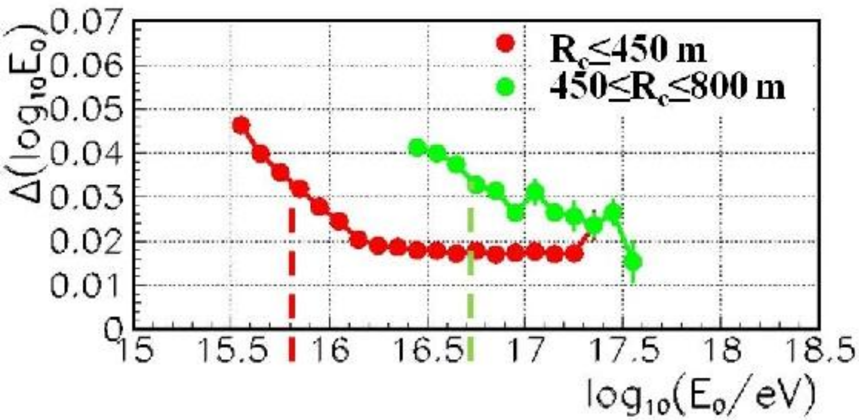
All four variables ($\mathbf{R_0}$, $\mathbf{R_{kn}}$, **a** and **c**), describing the ADF shape in the different ranges of core Distance, are related to a single parameter of the ADF shape – the steepness **b.**



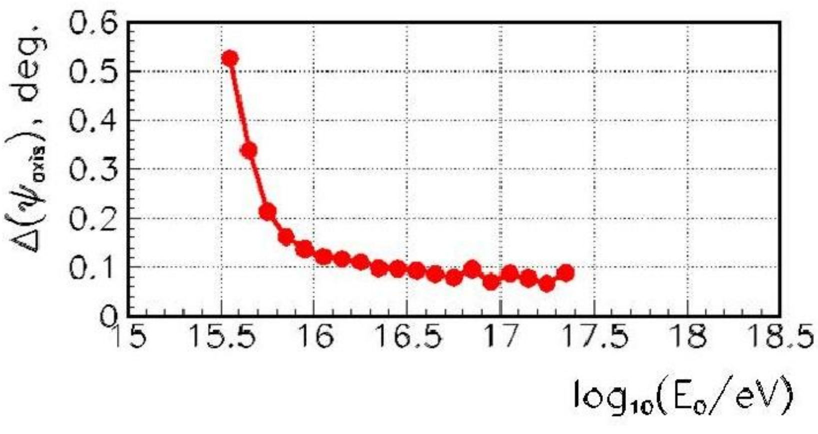
ICRC 2013



$\Delta(R_{core})$, m
$R_c \leq 450$ m
$450 \leq R_c \leq 800$ m

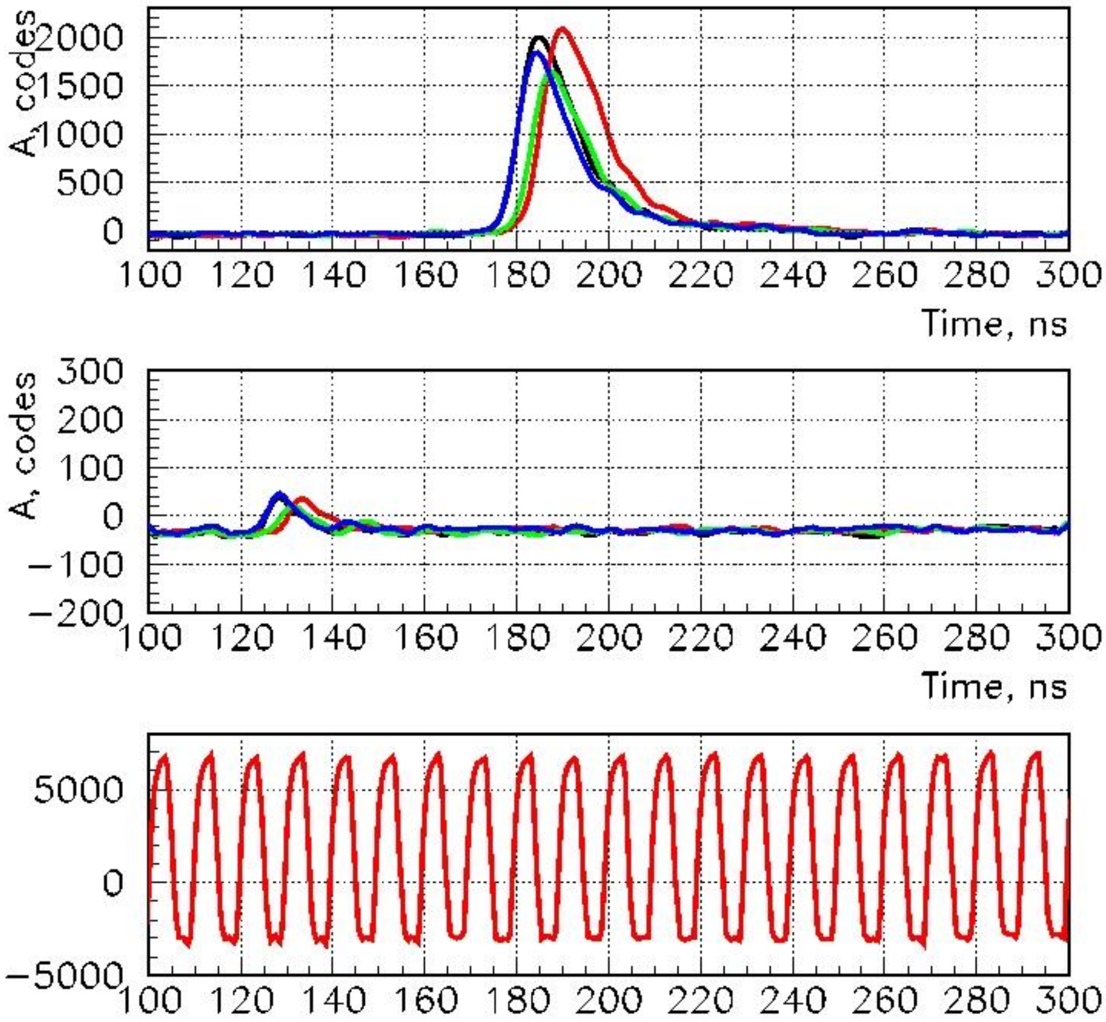


$\Delta(\log_{10}E_0)$
$R_c \leq 450$ m
$450 \leq R_c \leq 800$ m
$\log_{10}(E_0/eV)$

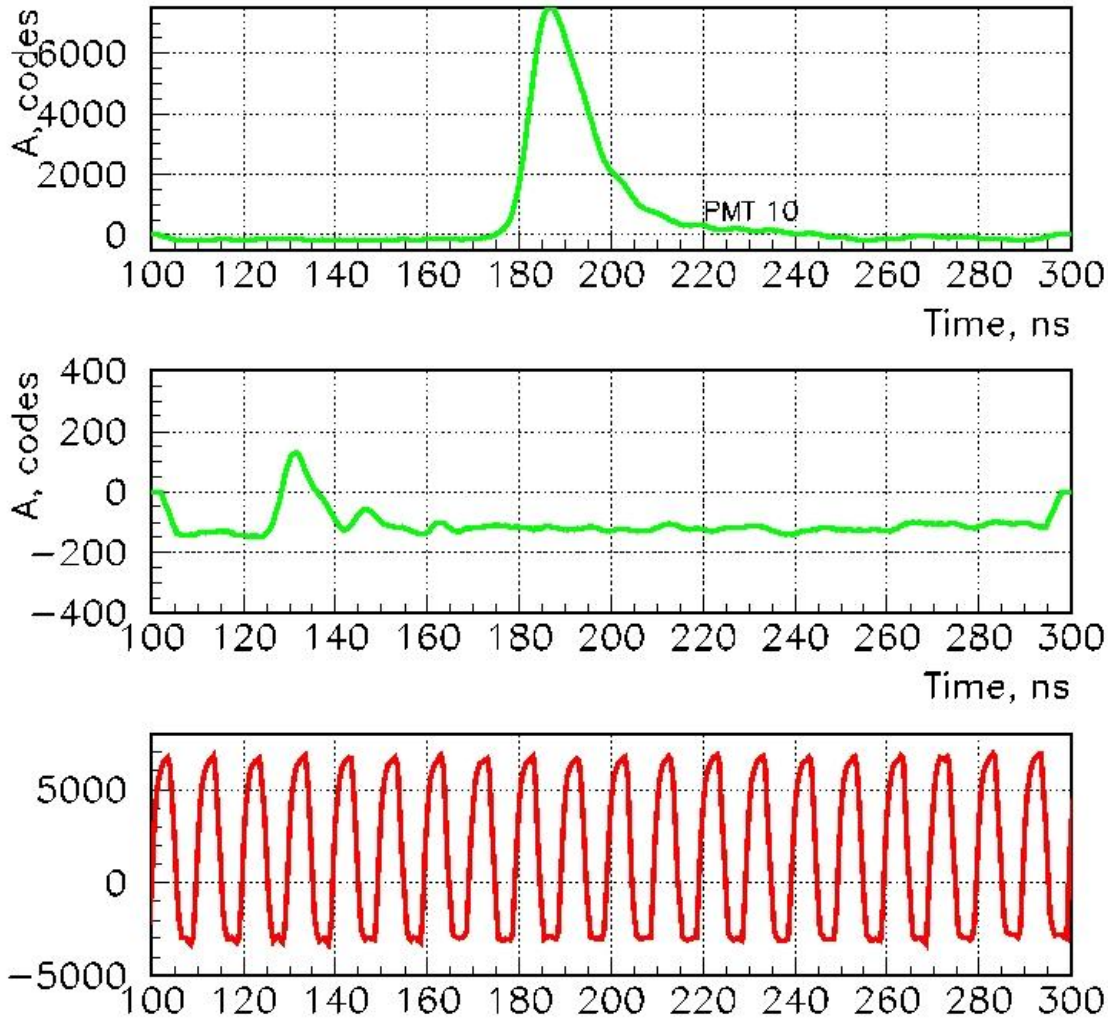


$\Delta(\psi_{axis})$, deg.
$\log_{10}(E_0/eV)$

Single PMT records at station 10



Station sum record
corect shift of partial traces for the shape correction



Data processing

Parameter reconstruction procedure:

1. Reconstruction of an arrival direction (theta, phy) with plane front model
2. Core position reconstruction by the center of gravity (4 stations closest to the center of gravity). Xc, Yc, Qmean
3. Core position by fitting of pulse amplitudes with ADF.
4. Arrival direction with the curved front model.
5. Removing of high deflections (> 500 ns).
6. Repetition of 4.
7. Removing of high deflections (> 6 ns).
8. Repetition of 4.

Data processing

4. Analysis of relative PMT delays in each station – “dt_pmt[date].dat”.
5. Shift of traces to correct the single PMT delay, summing of signals from anodes and dynodes, measuring of parameters of summed pulses – “prm18_2/NNsDDMMY.prm”
6. Relative amplitude calibration of anode channels and coefficients from dynode to anode – “cal18/calDDMM.dat”.

7. Merging of single station events into EAS – >=4 stations coincidence Result – “DDMMY_c4.tim” files.

Data processing

1. All data storage and processing is made at the server of SINP MSU now:
   a) TAIGA-HiSCORE
   b) Tunka-133
   c) Tunka-Grande

2. Viewing of separate traces corresponding to 44x4=176 PMTs. Analysis of operation quality – list of operating PMT – “lstpmt[date].dat”
3. Binary data decoding for every station and every DRS channel. Pulse parameters measuring: A, S, T_{front} (additional delay) – “[Ns]_[dateY].prm”.

2017-2018 data

1. Limitation of the trace length from 1024 to 400 points (leads to data volume decreasing to 2.5 times).
2. Control of the rate of 4 stations coincidence during the data registration and recording of preliminary "*.tim4" files.
3. Selection of double station coincidence events for storage and transfer. Recording of "*.tim2" files. Double coincidence selection decreases the data volume to about 3 times.

Total data volume decreasing is about 7.5 times.

35 nights with more or less good weather

180 hours

About $3 \cdot 10^8$ single station events