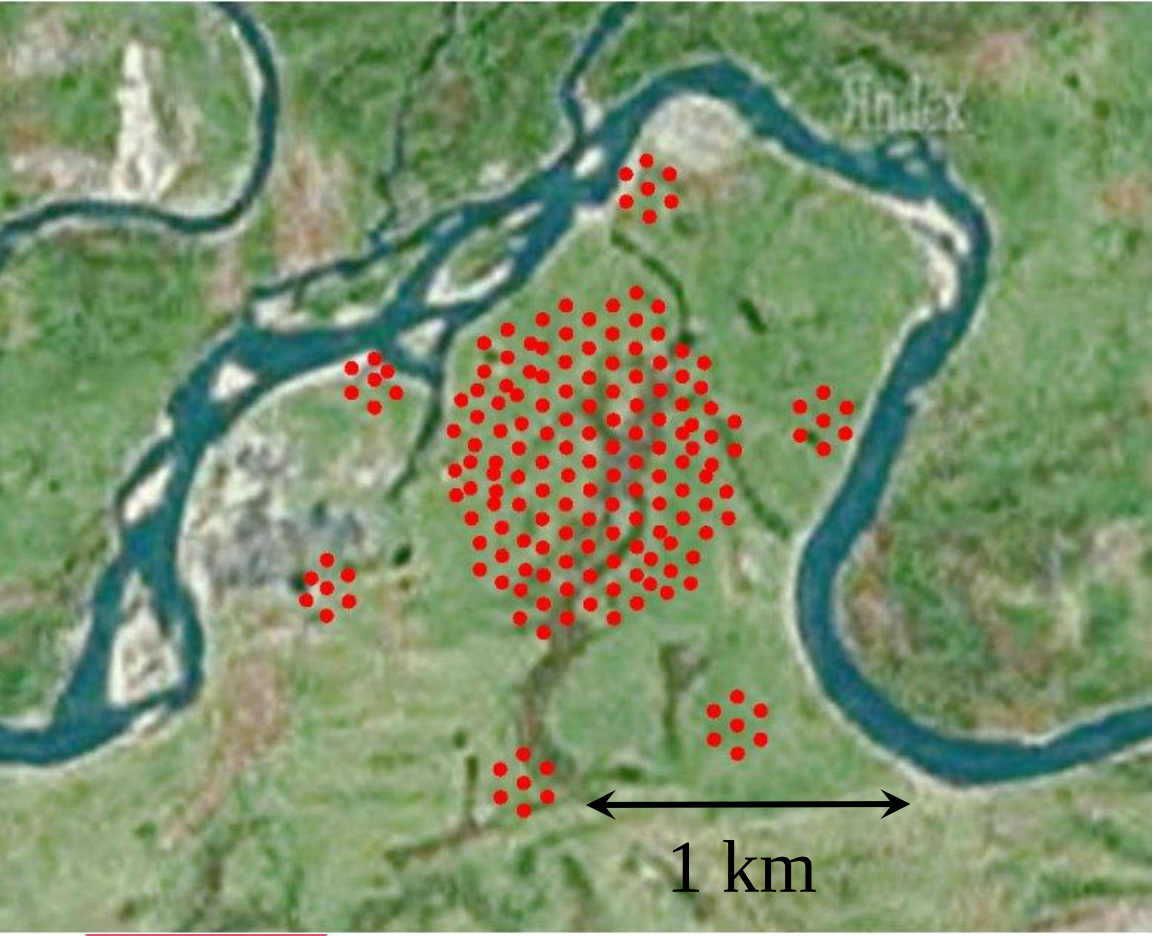
Primary Energy Spectrum by the Data of EAS Cherenkov Light Arrays Tunka-133 and TAIGA-HiSCORE.

Vasily Prosin for the Tunka and TAIGA Collaborations

ISCRA 26.06.2019

Tunka-133



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

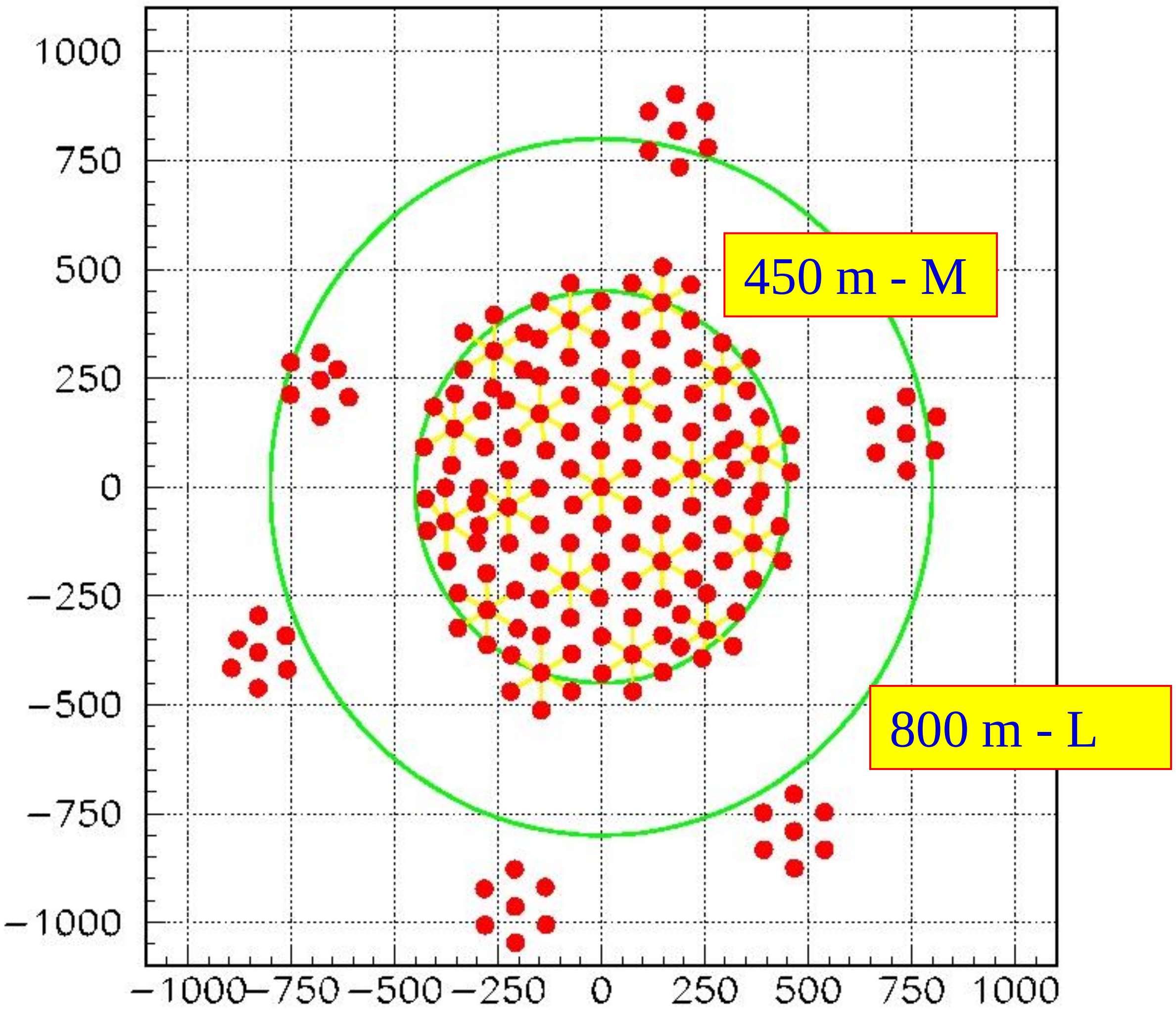
175 optical detectors
EMI 9350 and
HAMAMATSU Ø 20 cm

EXPERIMENTAL DATA

Tunka-133:

7 seasons, 350 nights, 2175 h, ~$1.5 \cdot 10^7$ single cluster events
100% effective registration:
~375,000 events with $E_0 > 6 \cdot 10^{15}$ eV,
~4,200 events with $E_0 > 10^{17}$ eV

Effective areas

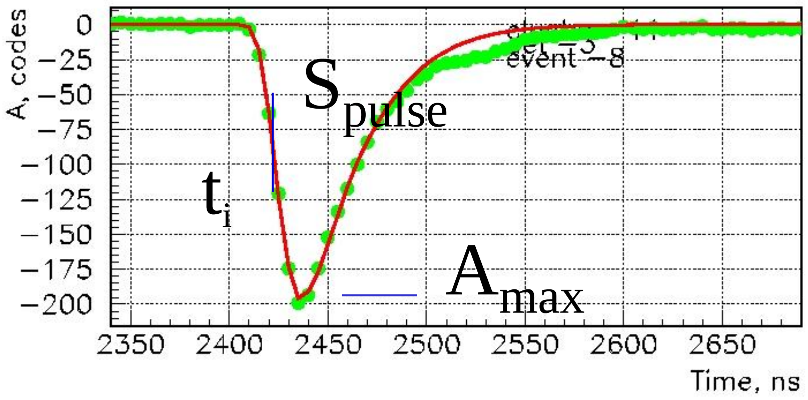


Tunka-133 single detector readout:

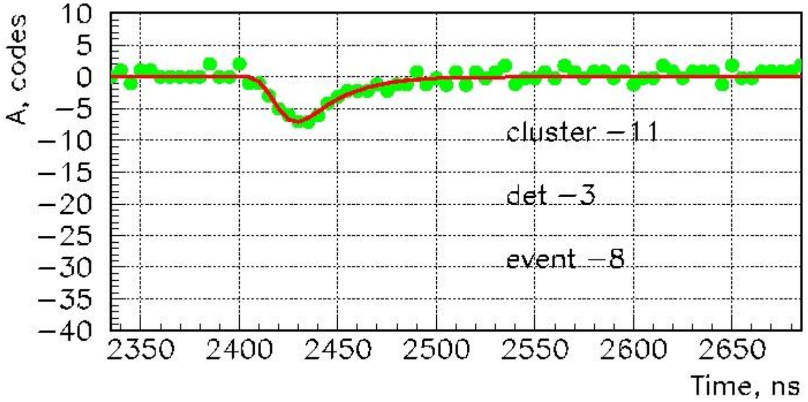
Fitting of the pulse and measuring of the parameters: $Q = c \cdot S_{pulse}$, A_{max}, t_i , $\tau_{eff} = S/A/1.24$

Time step = 5 ns

anode:

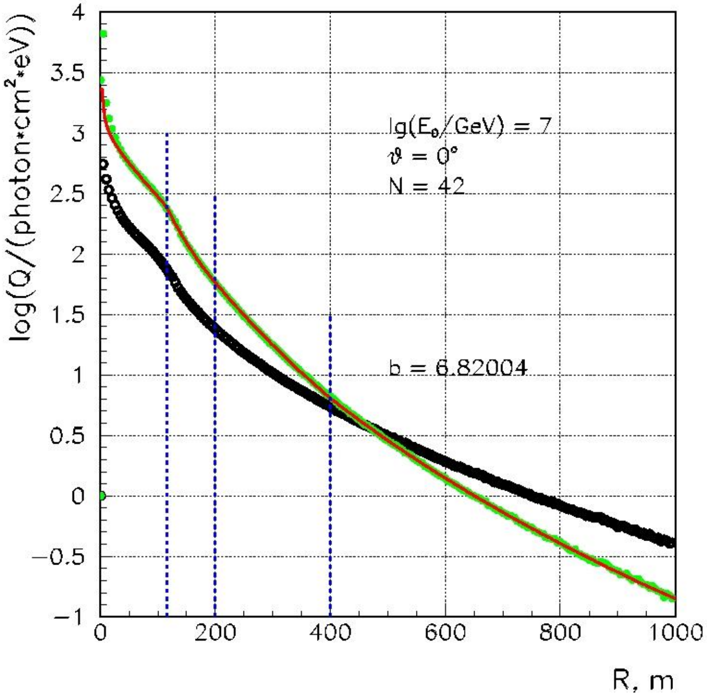


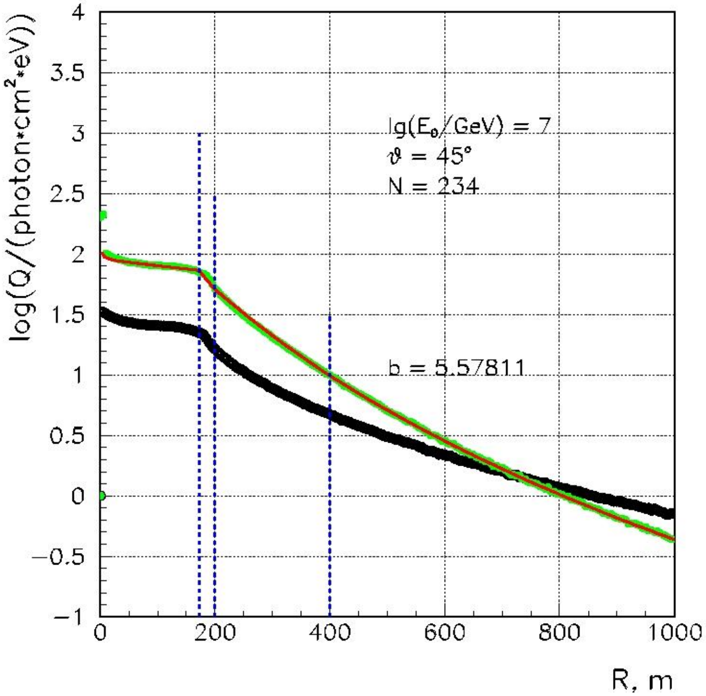
dynode:



EAS parameters reconstruction

CORSIKA: Fitting functions – LDF and ADF



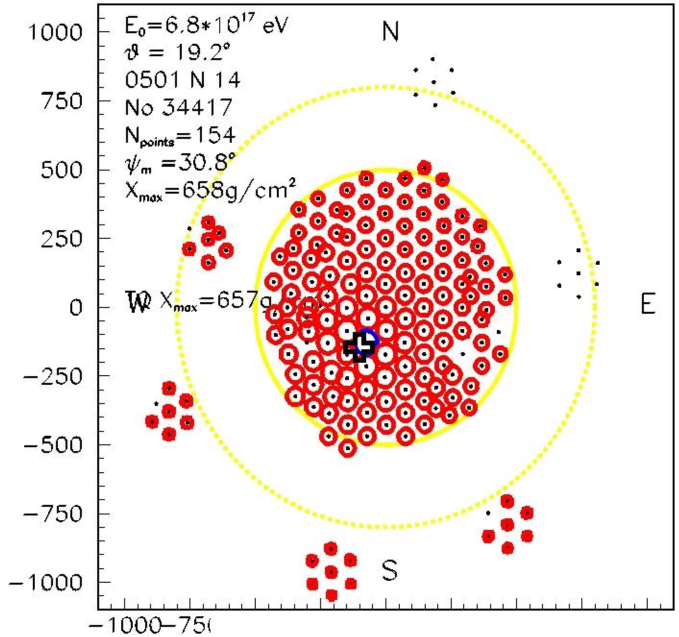


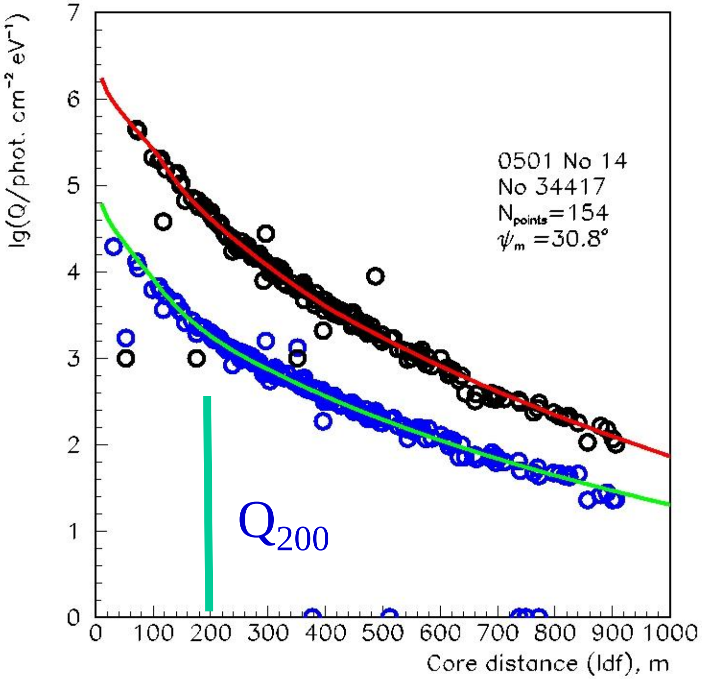
ADF: **$A(R) = A(400)\cdot((R/400+1)/2)^{-bA}$ steepness**: **b_A**

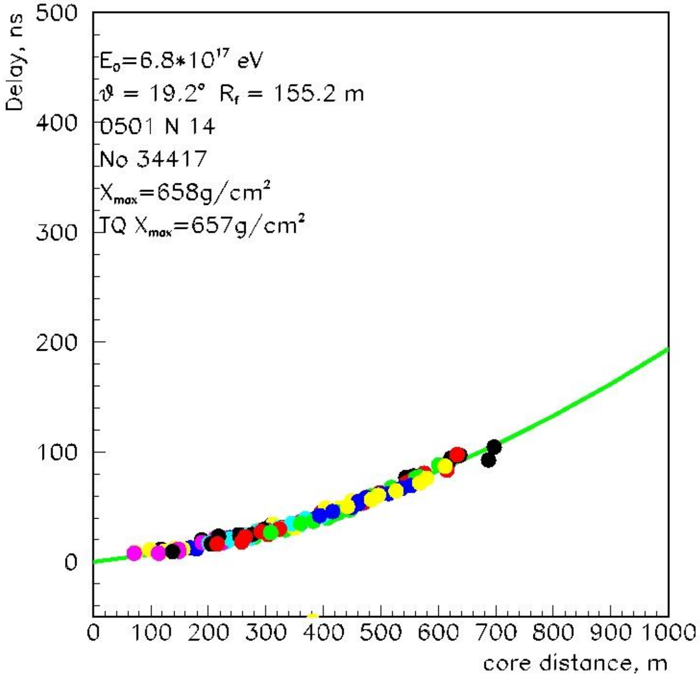
LDF: **$Q(R) = Q(300)\cdot((R/300+1)/2)^{-bQ}$** steepness: **$b_Q$**

$b_A > b_Q$

An Example of Tunka-133 event reconstruction







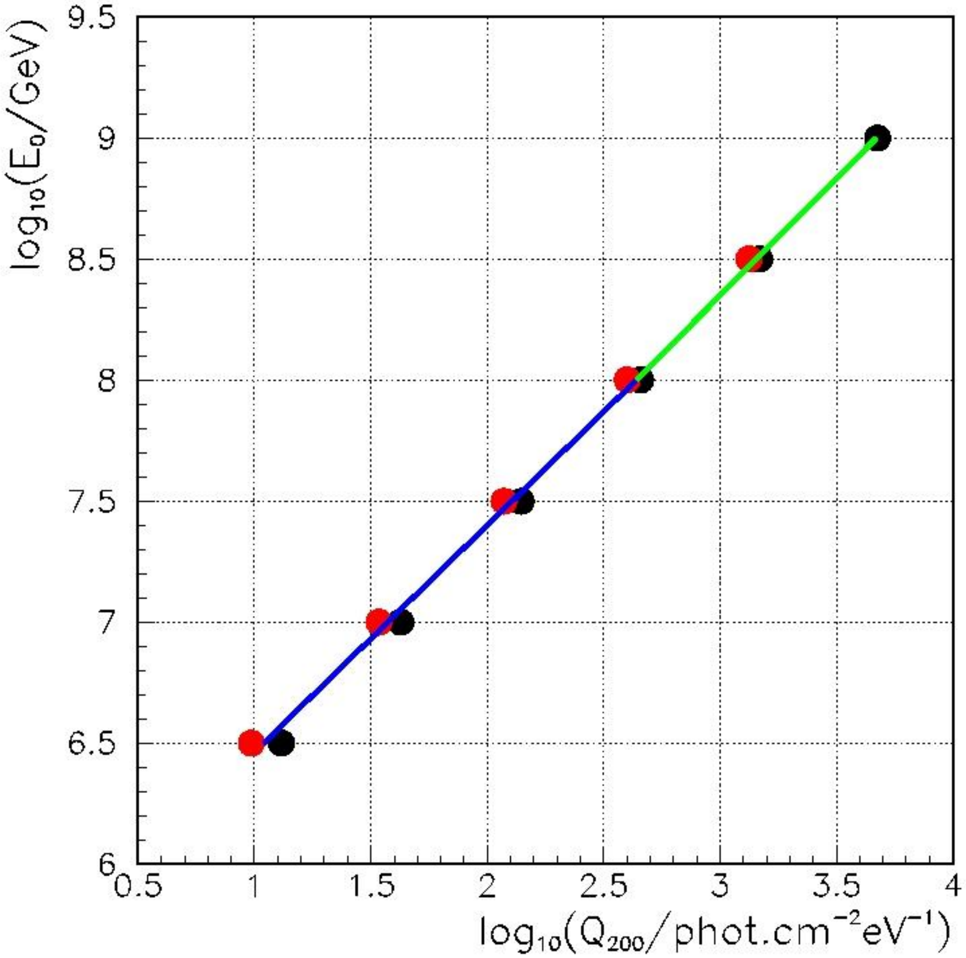
EAS paramerters reconstruction by Cherenkov light flux density Q_{200}

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

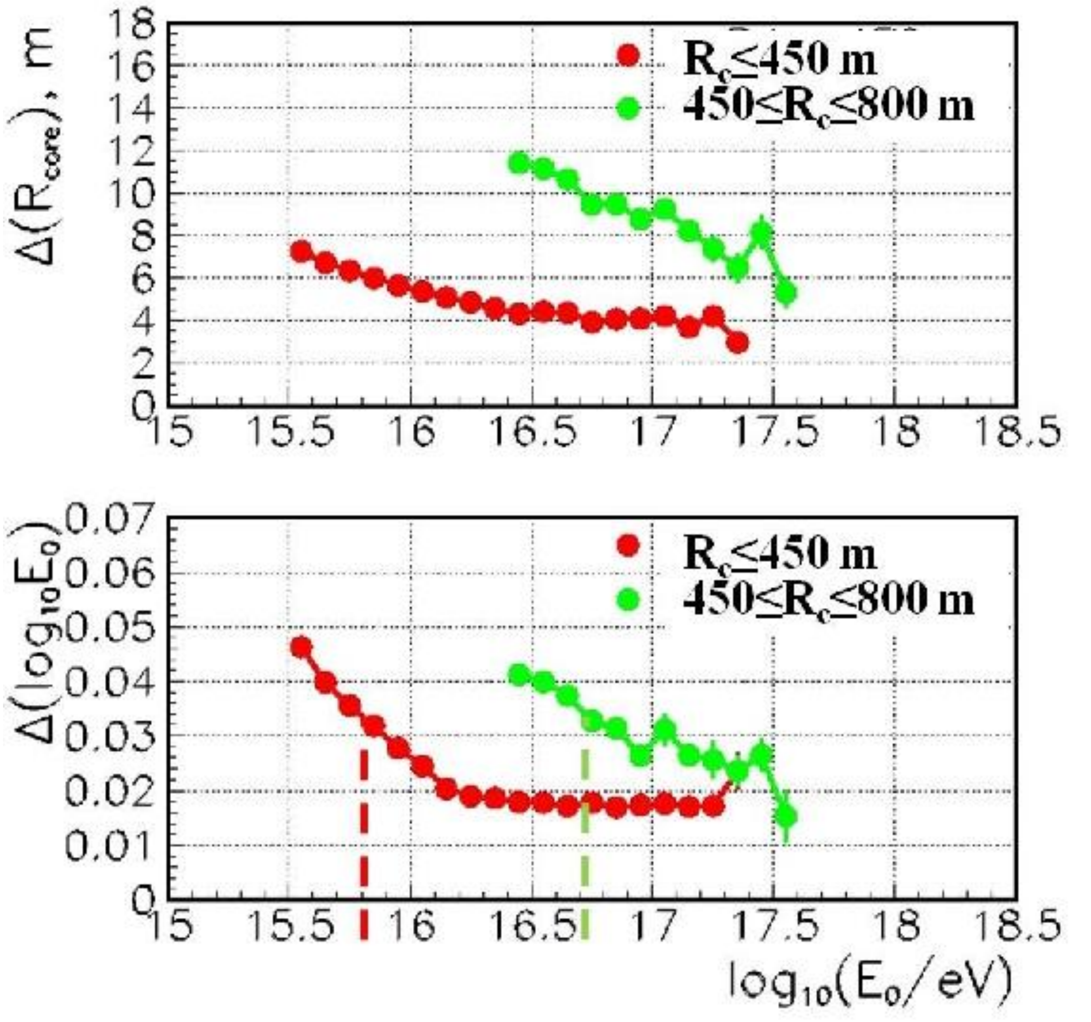
$$E_0 = C_1 \cdot Q_{200}^{0.94}, \quad E_0 < 10^8 \text{ GeV}$$

$$E_0 = C_2 \cdot Q_{200}^{0.95}, \quad E_0 > 10^8 \text{ GeV}$$

Simulated composition:
p – 50%, Fe – 50%, $E0 < 10^9$ GeV
p – 100%, $E0 = 10^9$ GeV

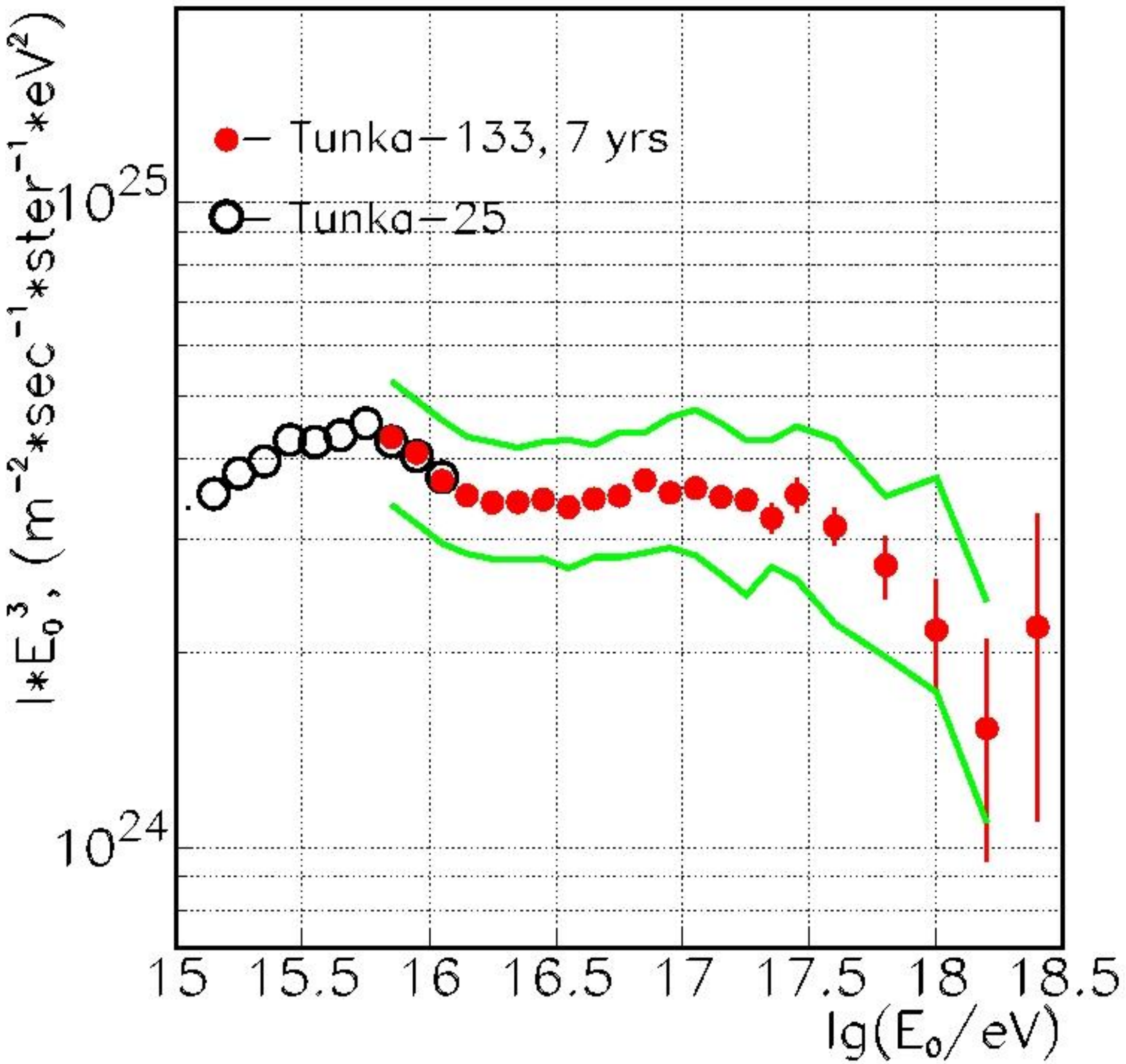


Relative accuracy of EAS parameters reconstruction



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



TAIGA - collaboration

Germany

Hamburg University (Hamburg)
DESY (Zeuthen)
MPI (Munich)

Italy

Torino University (Torino)

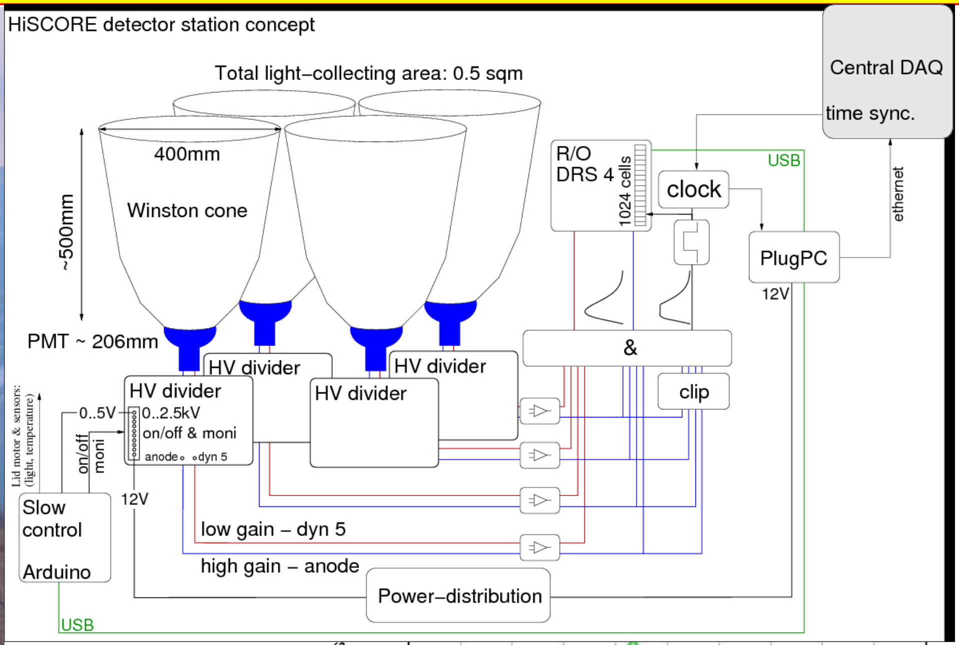
Romania

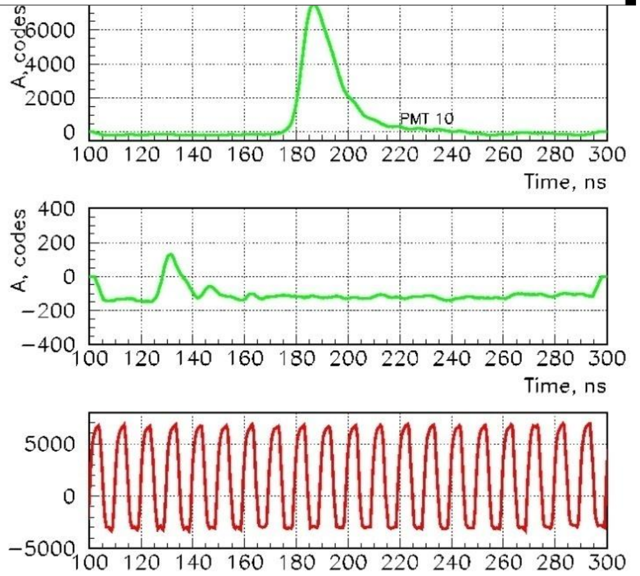
ISS (Bucharest)

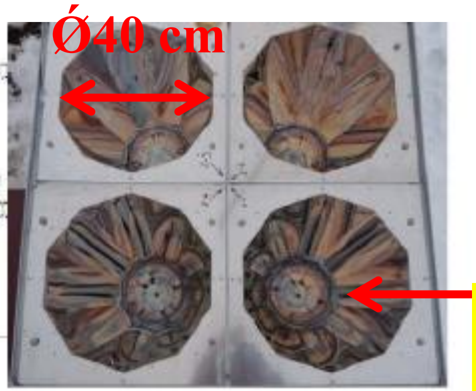
Russia

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

Low threshold wide angle station





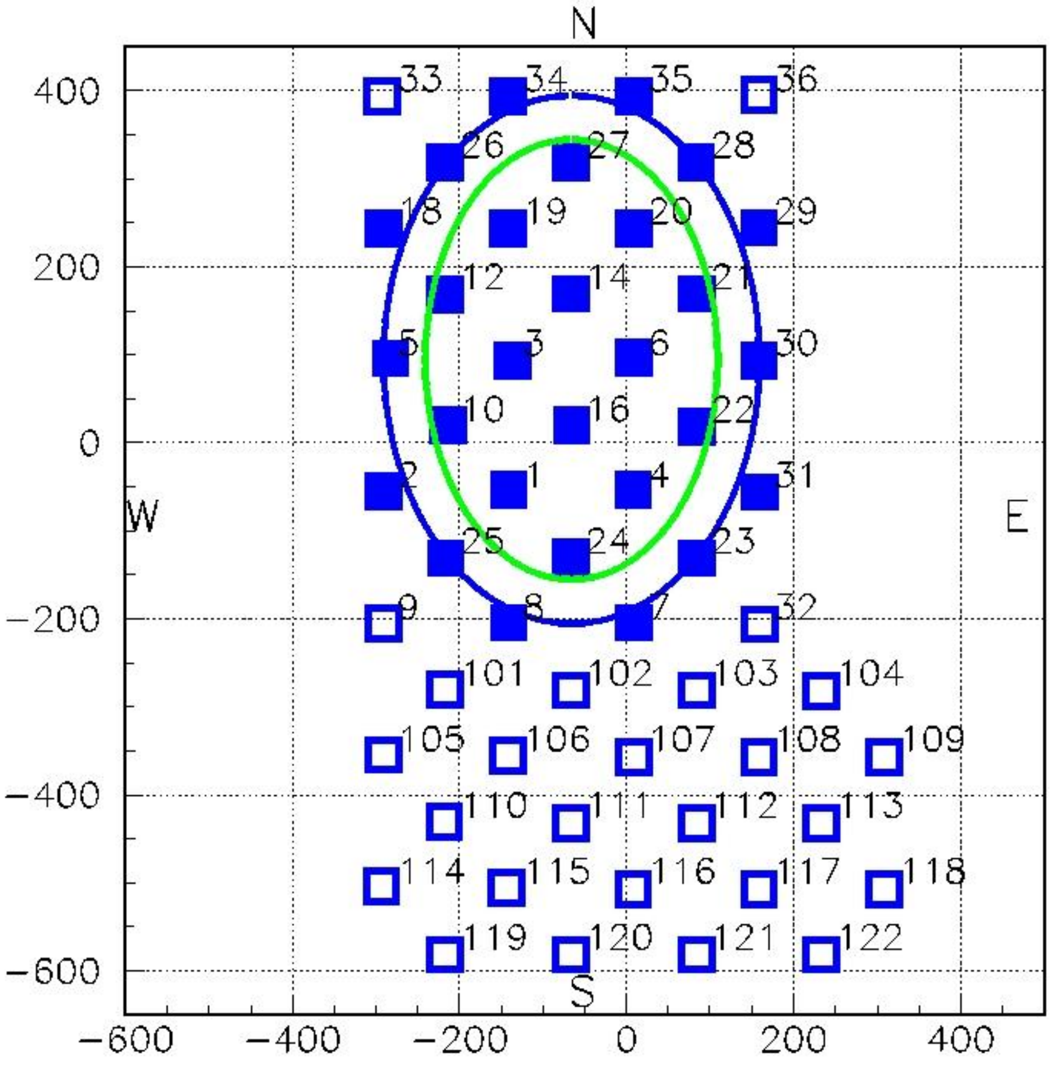


Digitized with DRS-4.
Step = 0.5 ns
Synchronization and data taking via optical cable

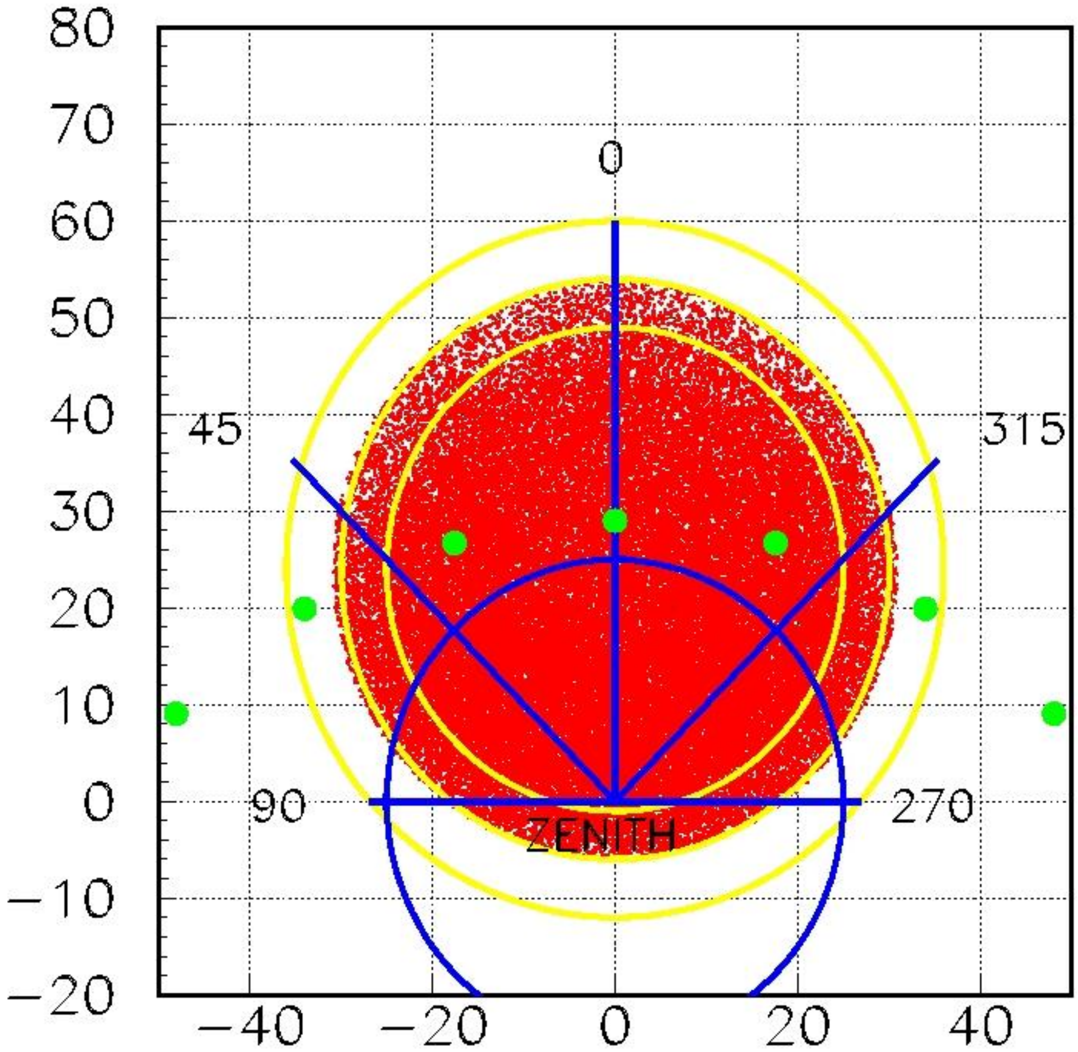
Winston cone and PMT with 20 cm photocathode diameter

S tot = 0.5 m^2

Stations layout 2018 - 2019



Field of view



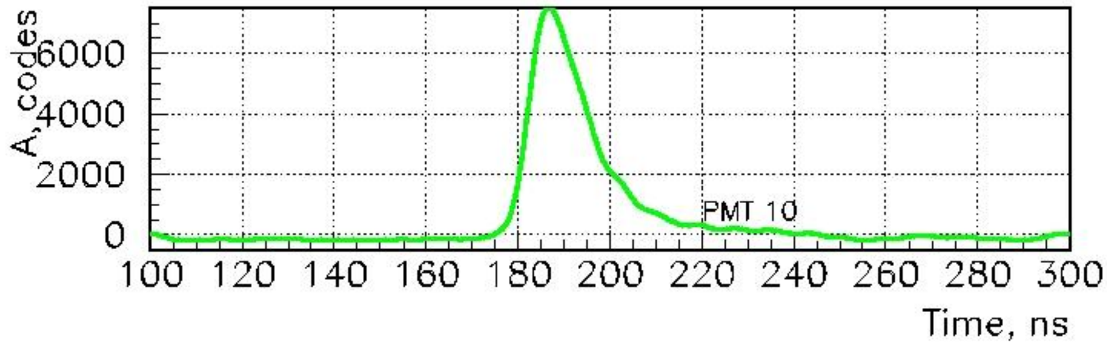
Crab trajectory

Azimuth angle

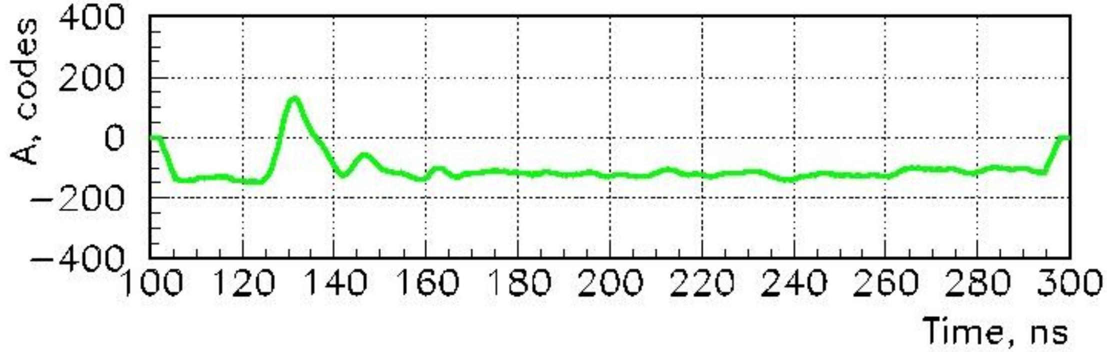
Zenith angle

HiSCORE station sum record 2017-2019

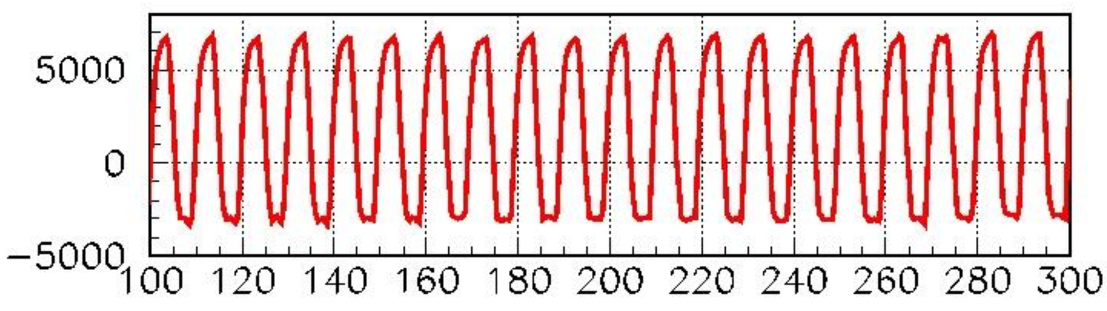
anode:



dynode:



synchronisation:



EXPERIMENTAL DATA

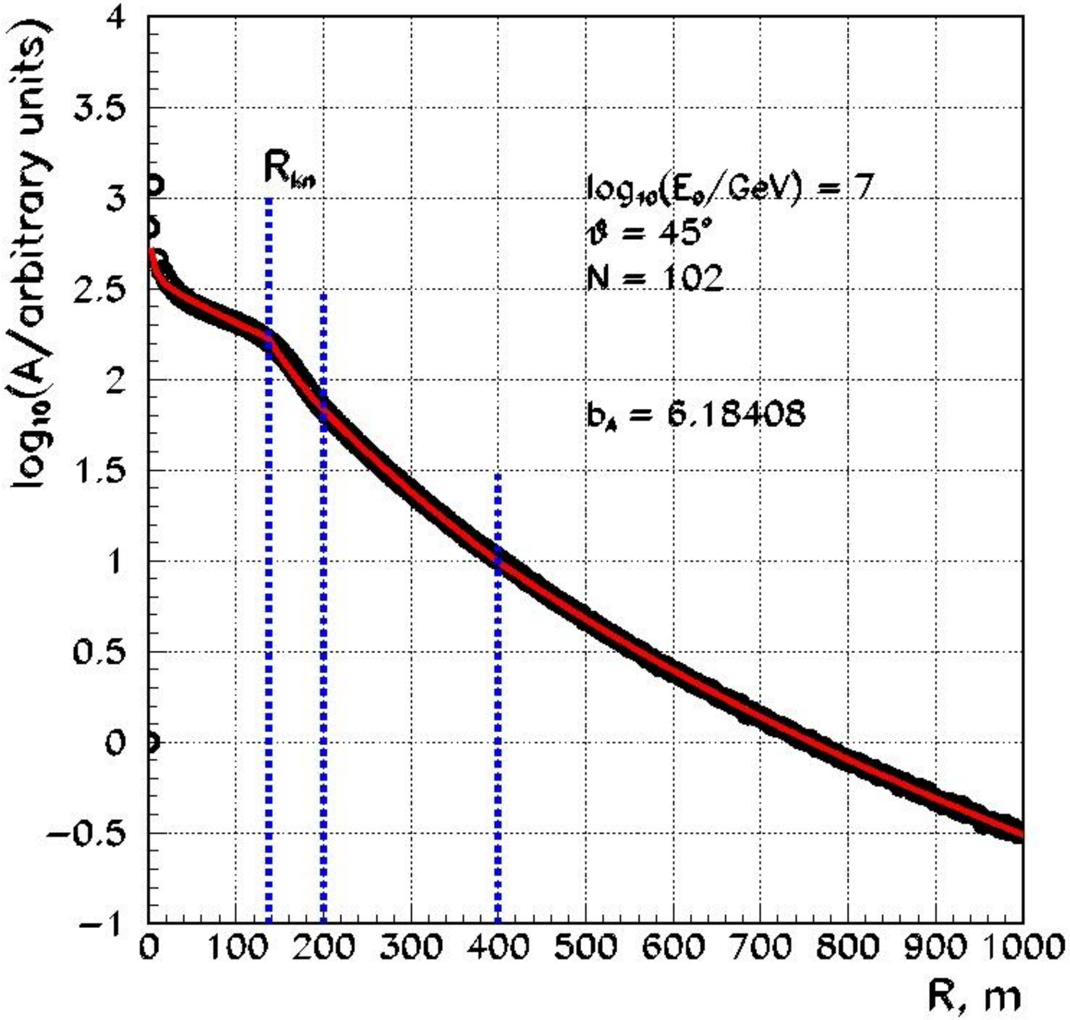
TAIGA-HiSCORE:

season 2017-2018, 1st cluster – 28 stations, 2nd cluster – 13 stations
35 nights, 180 h, $\sim 3 \cdot 10^8$ single station events
100% effective registration:

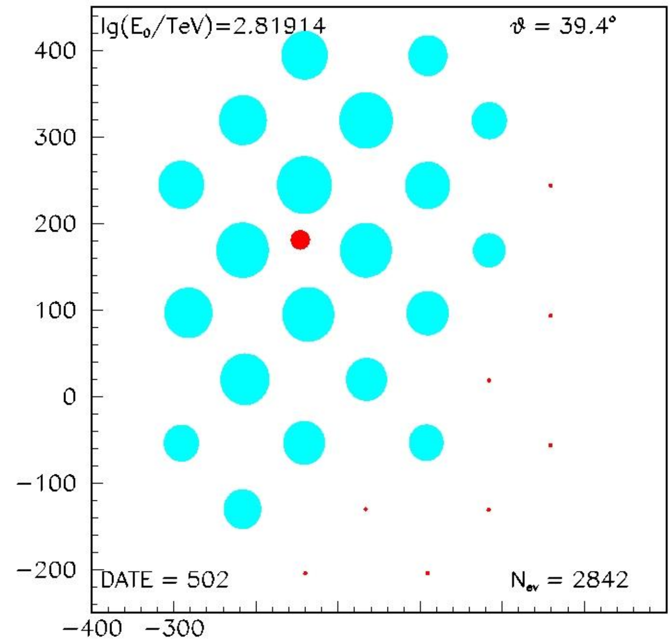
$2 \cdot 10^{14} - 3 \cdot 10^{14}$	~29,000 (one night 28.10.2018, Q_{70})
$3 \cdot 10^{14} - 10^{15}$	~700,000 (35 nights, Q_{70})
$10^{15} - 10^{17}$	~170,000 (35 nights, Q_{200})

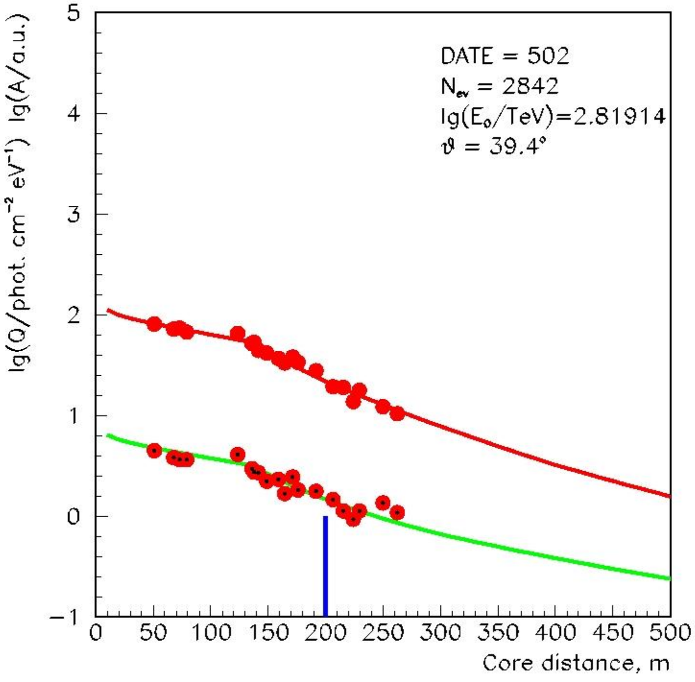
Season 2018-2019. 1st cluster – 32 stations, 2nd cluster – 22 stations
~ 40 nights, ~ 250 h
Processing and analysis is in progress.

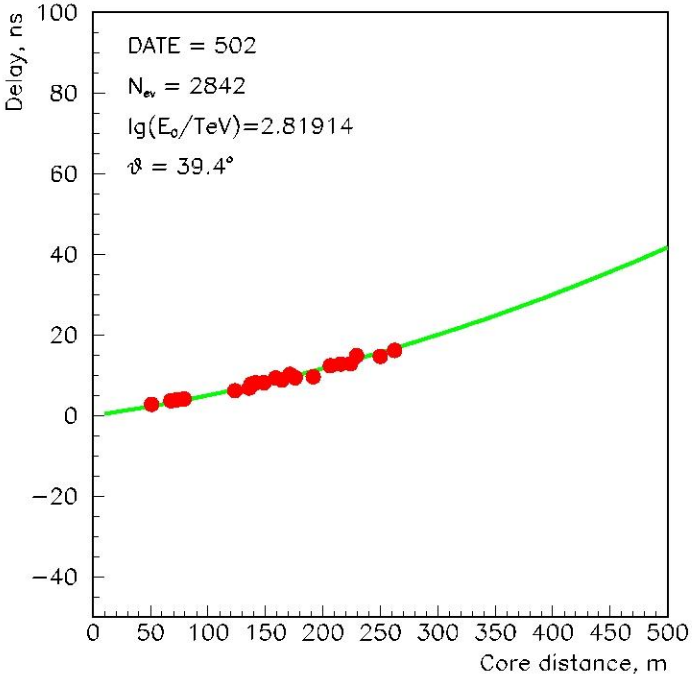
Amplitude – Distance Function (ADF)



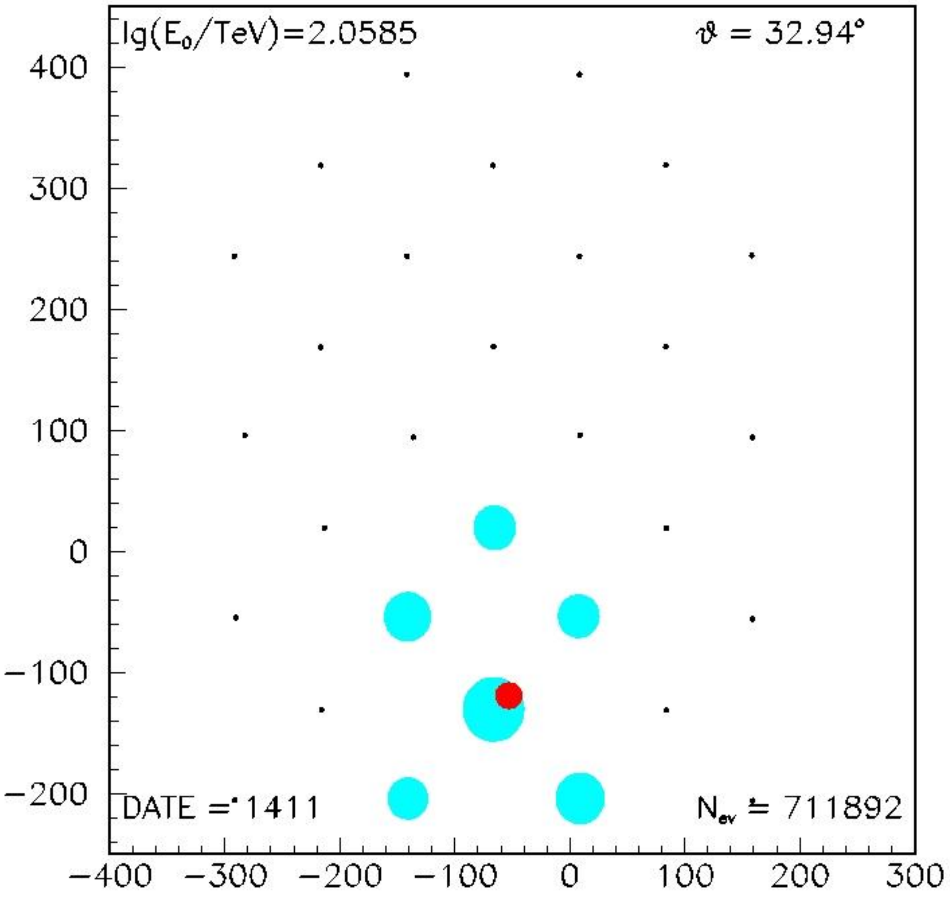
An Example of TAIGA-HiSCORE event reconstruction







Gravity Center Reconstruction



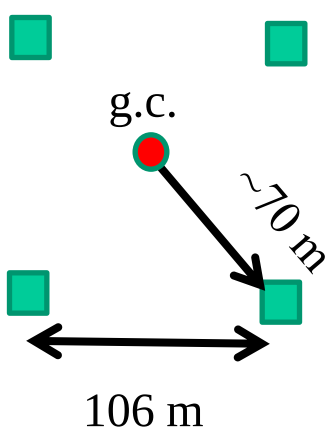
EAS parameters reconstruction by Q_{70}

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.

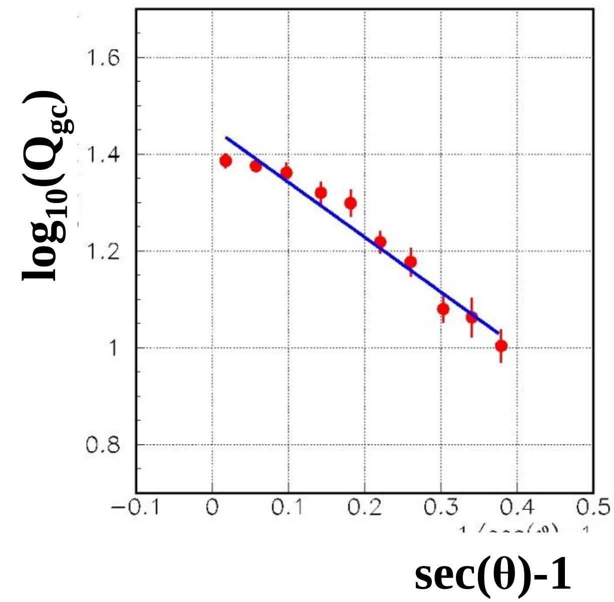
Q_{gc} is mean value by these 4 stations

Minimal event configuration:

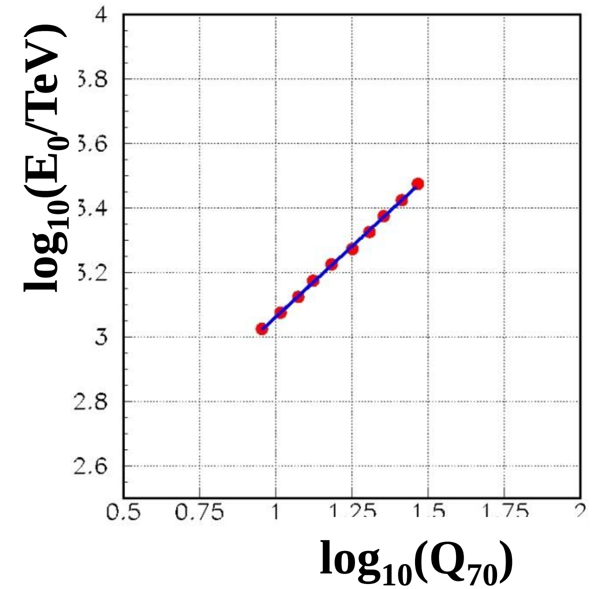


Experimental correlations, obtained for the energy range $10^{15} – 3\cdot10^{15}$ eV, are extrapolated to lower energy:

$$Q_{70} = Q_{gc}\cdot 1.1(\sec(\theta)-1) :$$



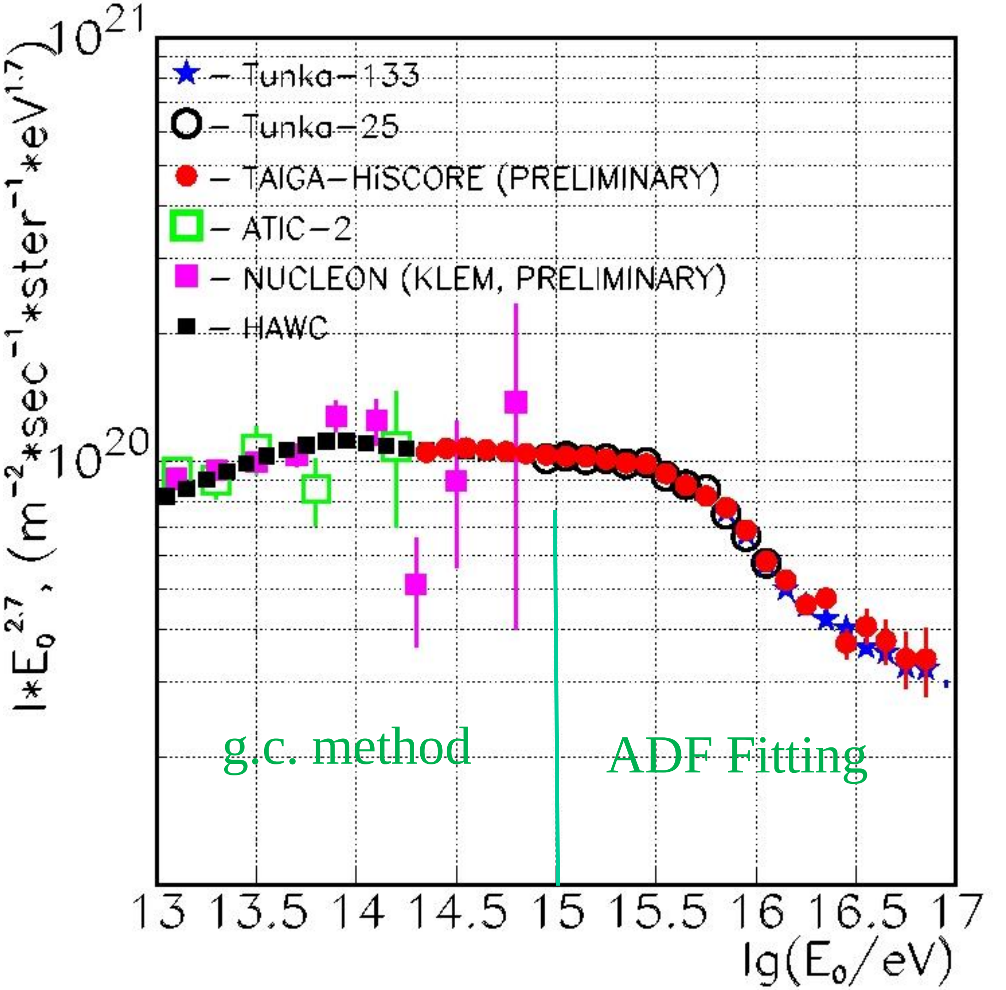
$$E_0 = C\cdot Q_{70}^{0.88} :$$



HiSCORE spectrum 2018

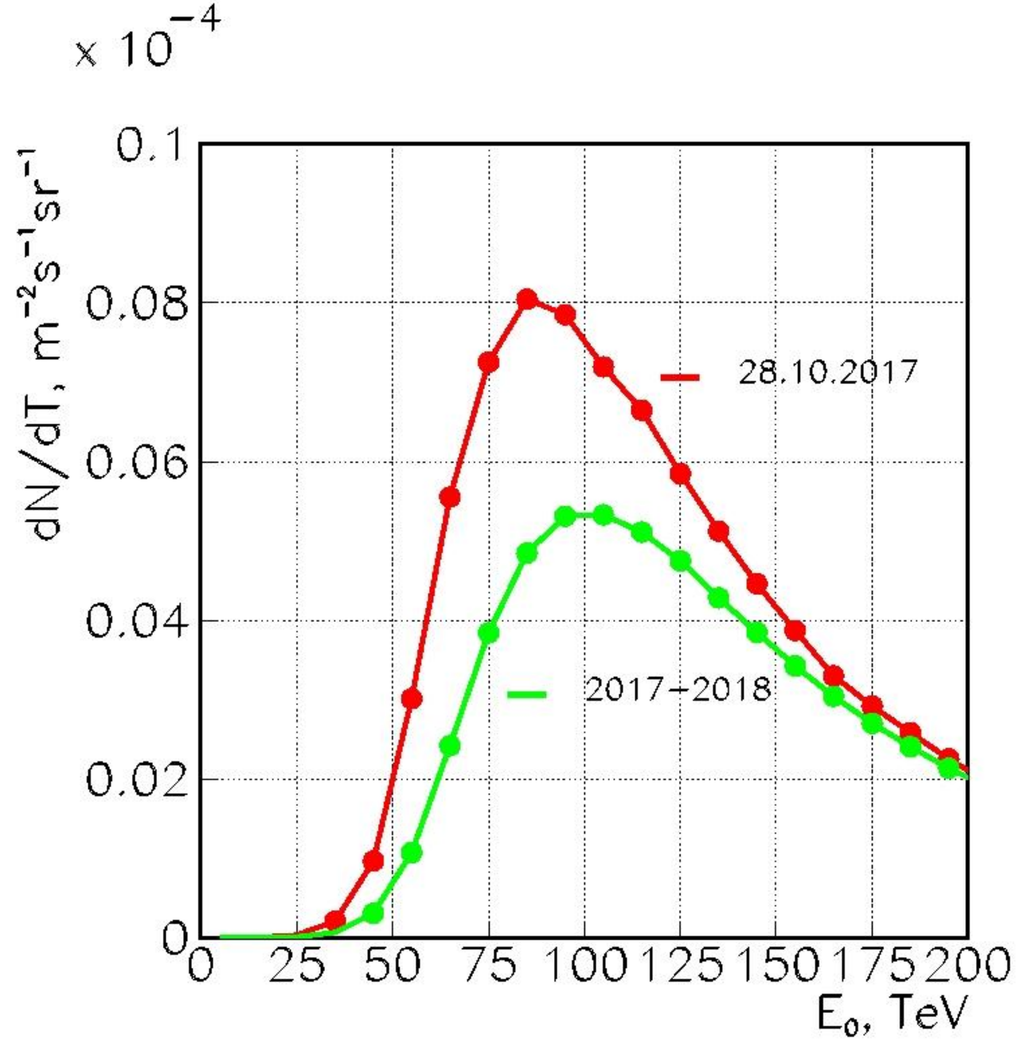
G.c. method:
2017 – 2018
~180 h
~ 10^6 events

ADF fitting:
2016 – 2018
~ 500 h
~ 10^5 events



E_0 Distribution

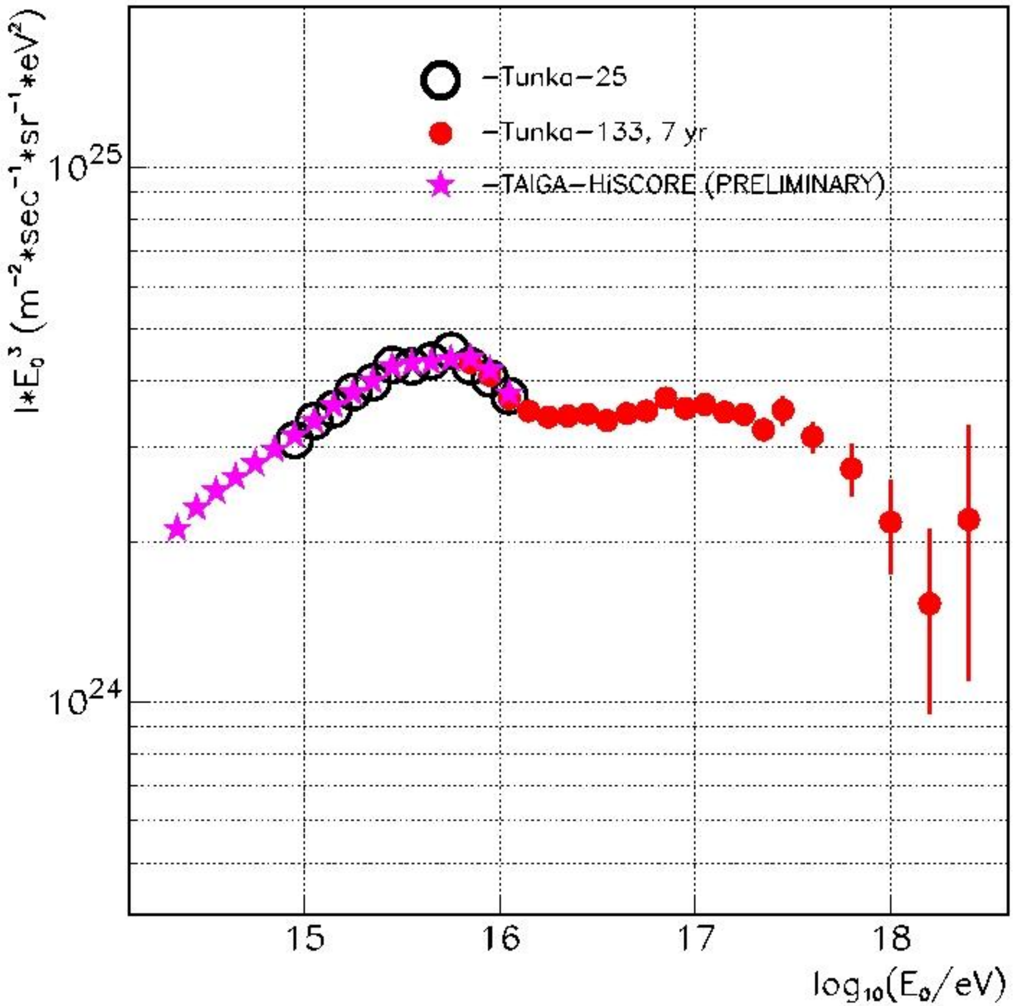
$E_\gamma = E_c/1.8$



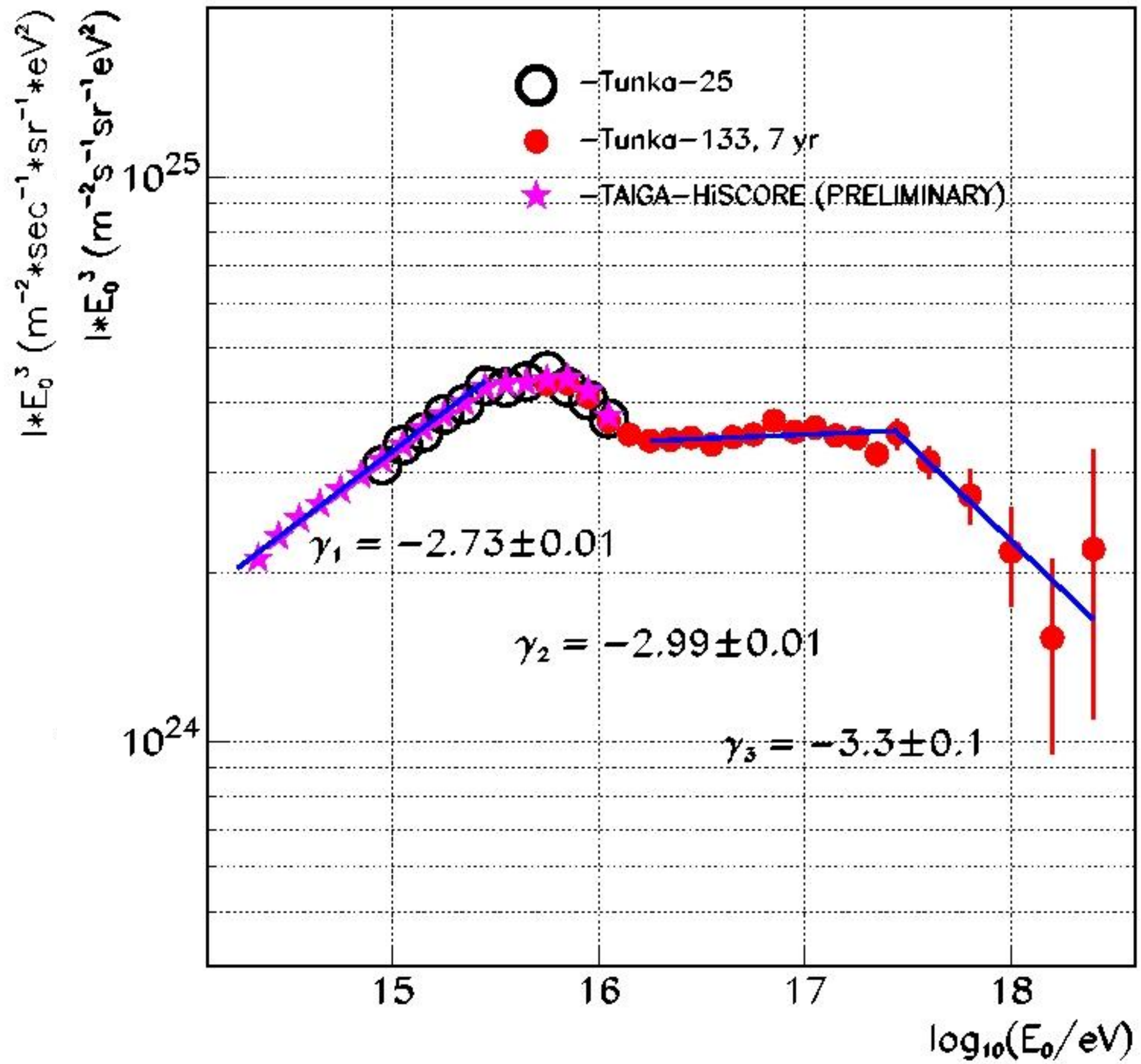
Tunka Primary Energy Spectra with EAS Cerenkov Light

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

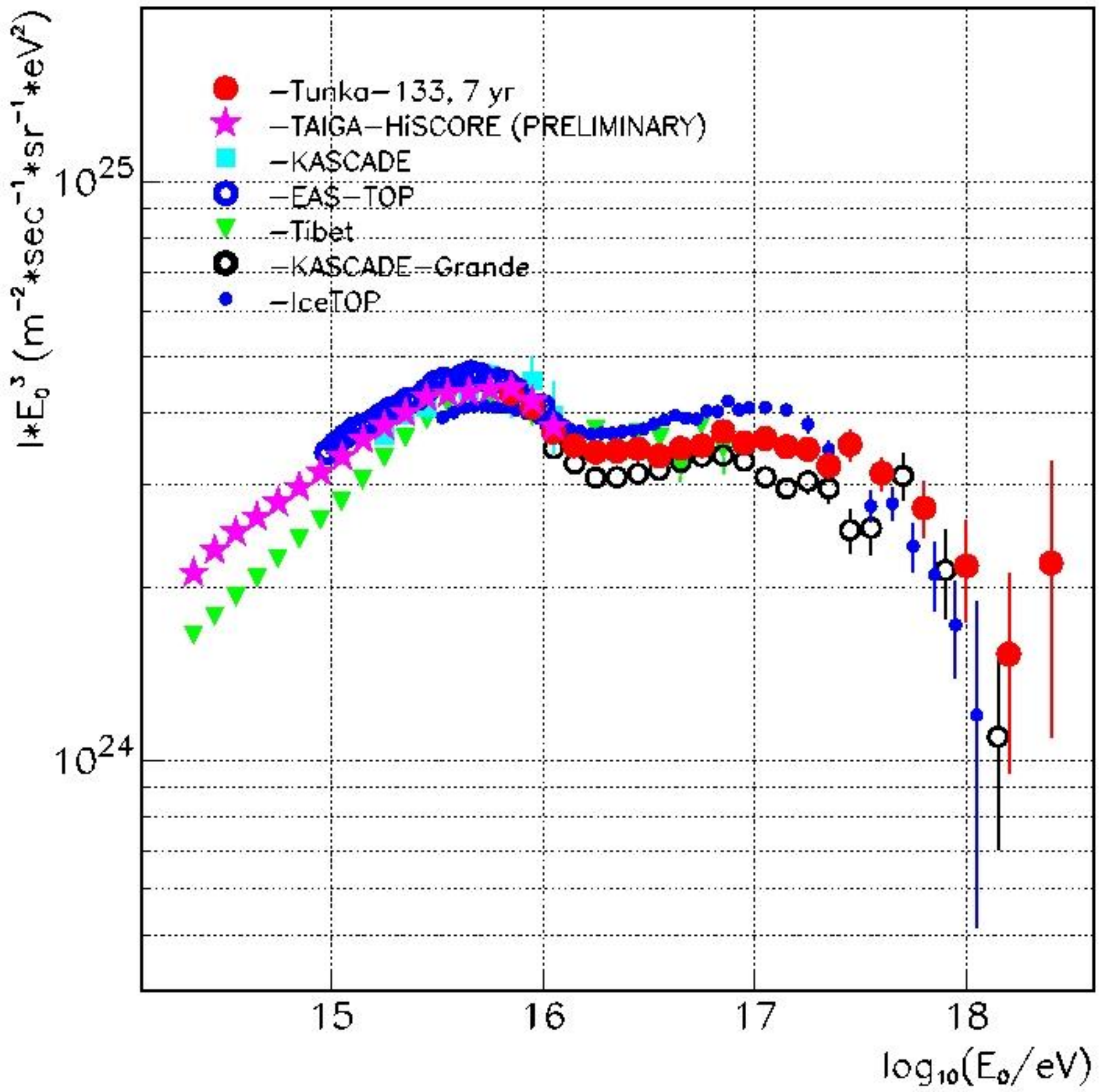
TAIGA-HiSCORE:
35 clean moonless nights
180 h
~900,000 events
with ~100% efficiency



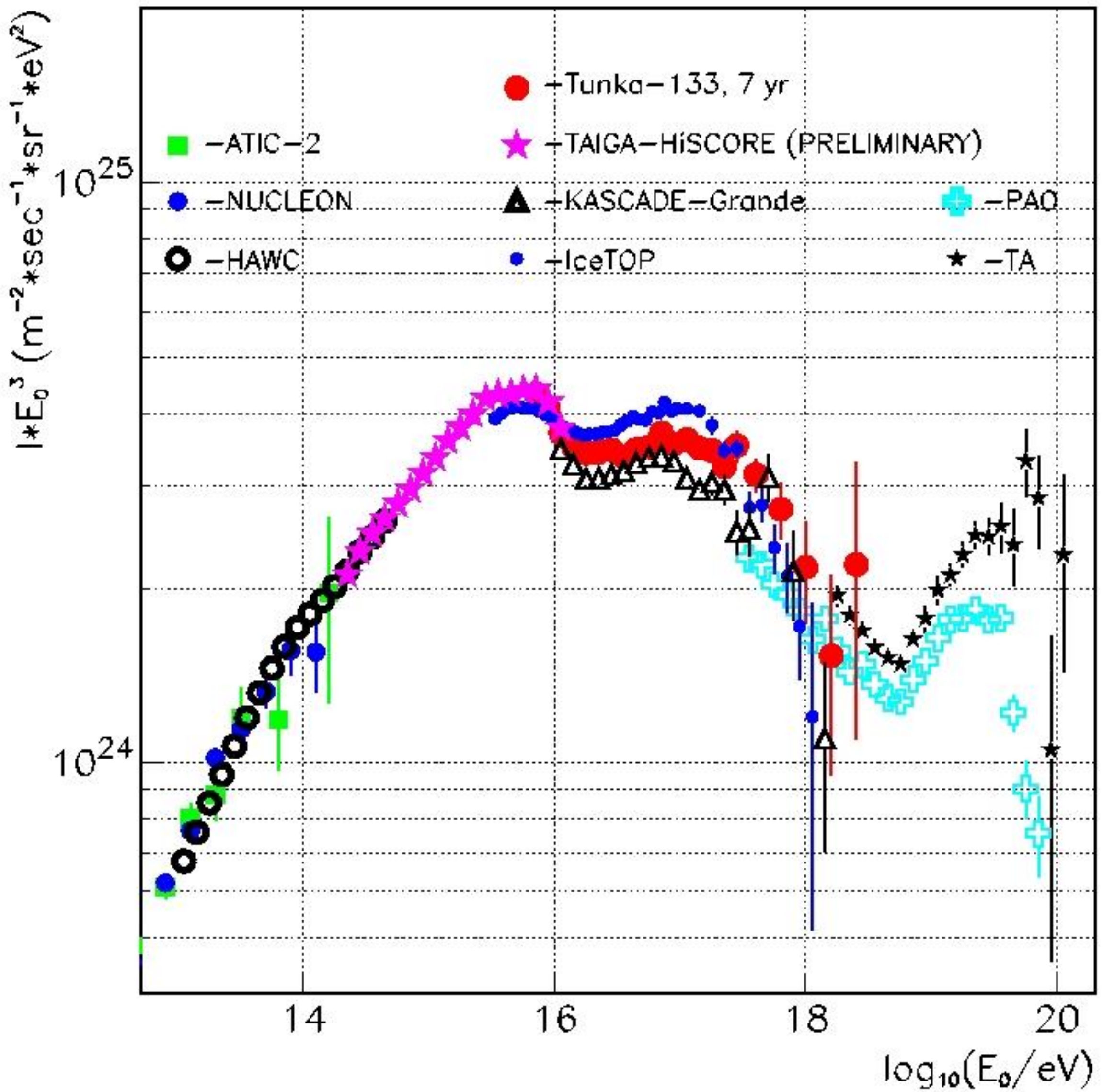
Energy spectrum: power law fitting



Energy spectrum comparison with intermediate enery experiments



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



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^{13} eV) to extremely high energy (10^{20} eV)

Thank you!