PRIMARY COSMIC RAYS ENERGY SPECTRUM BY THE 3 YEARS DATA OF THE TAIGA-HiSCORE ARRAY

ISCRA-2025

V. V. PROSIN for the TAIGA Collaboration

Грант РНФ № 23-72-00016

The TAIGA experiment is a hybrid installation for high–energy gamma-ray astronomy and cosmic ray physics in the Tunka Valley.

Directions of the stations

2021 Oct – 2022 Apr – Stations are tilted 25° to the South

2022 Oct – 2023 Apr – Stations are directed to the Zenith

2023 Sep – 2023 Oct – Stations are directed to the Zenith

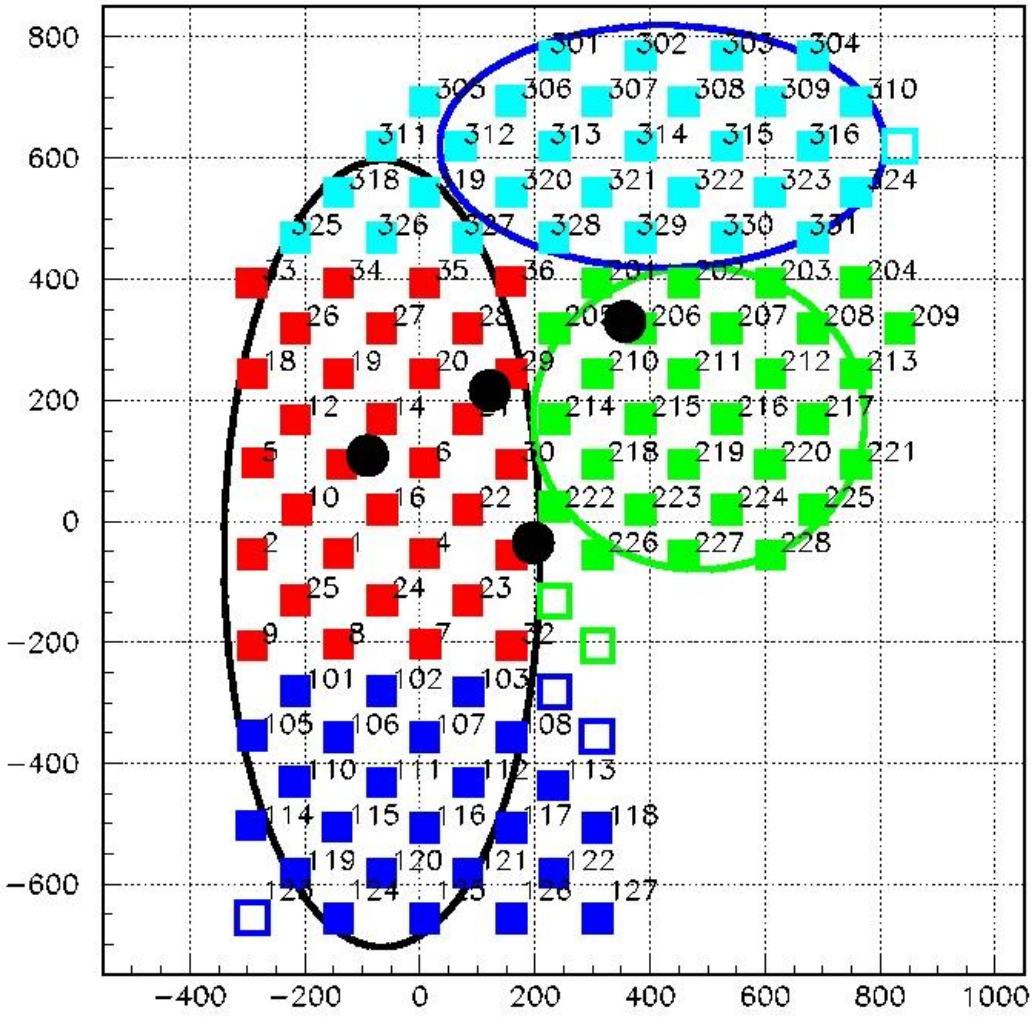
2023 Nov – 2024 Apr – Stations are tilted 25° to the South

TAIGA-HISCORE 2021 - 2024

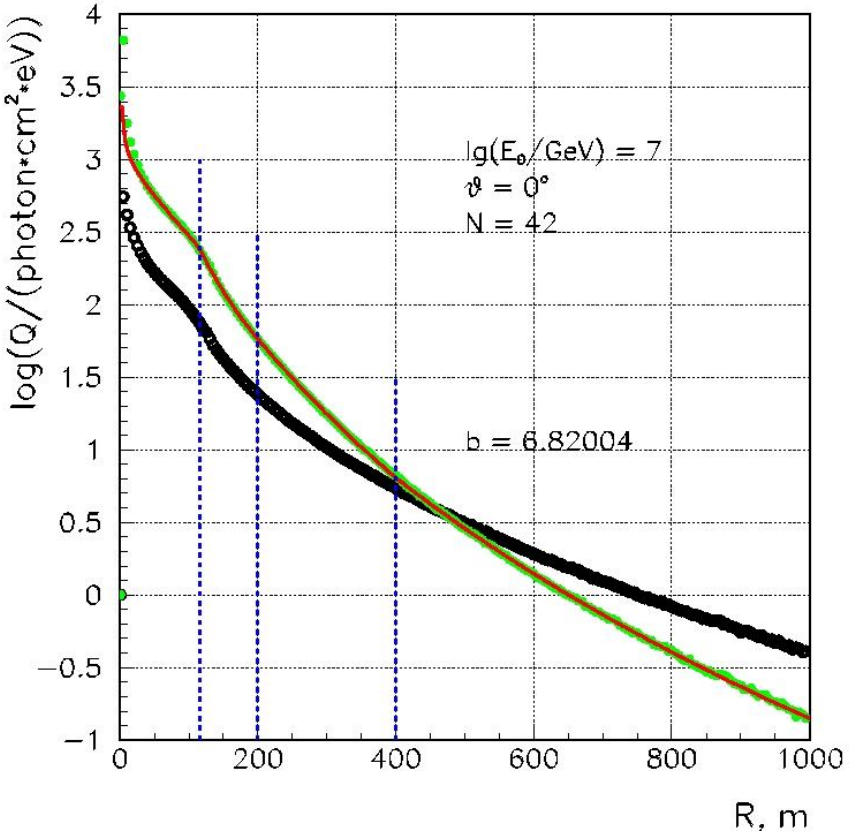
Layout of 4 clusters and 4 IACTs.

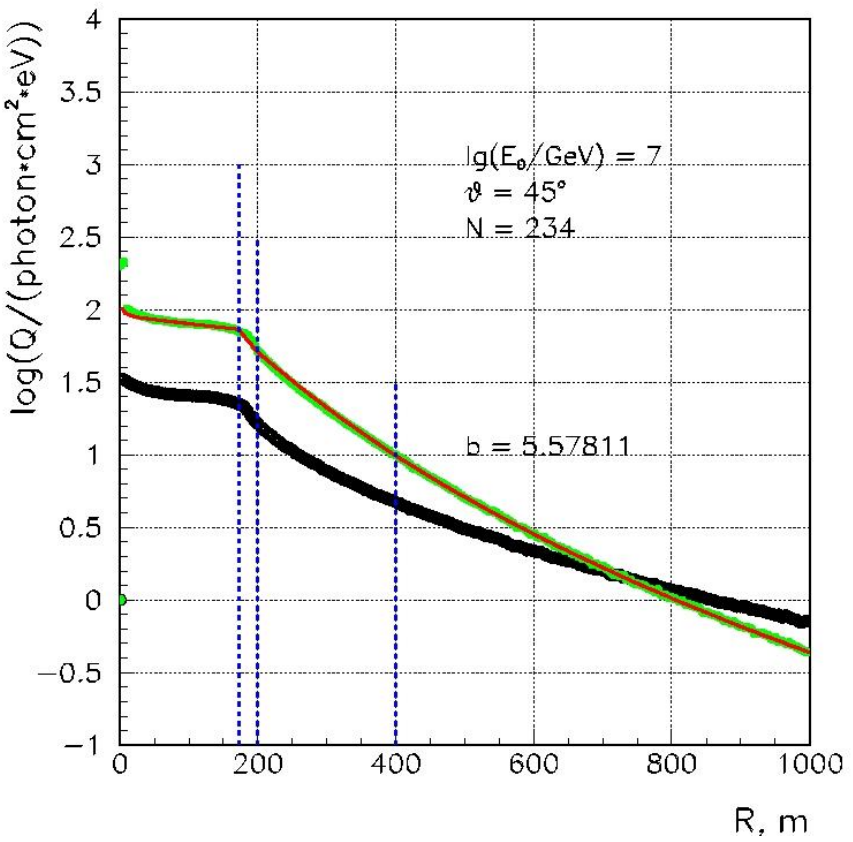
The total number of operating stations is 114.

Effective area 1.03 km^2



CORSIKA: Functions – LDF and ADF





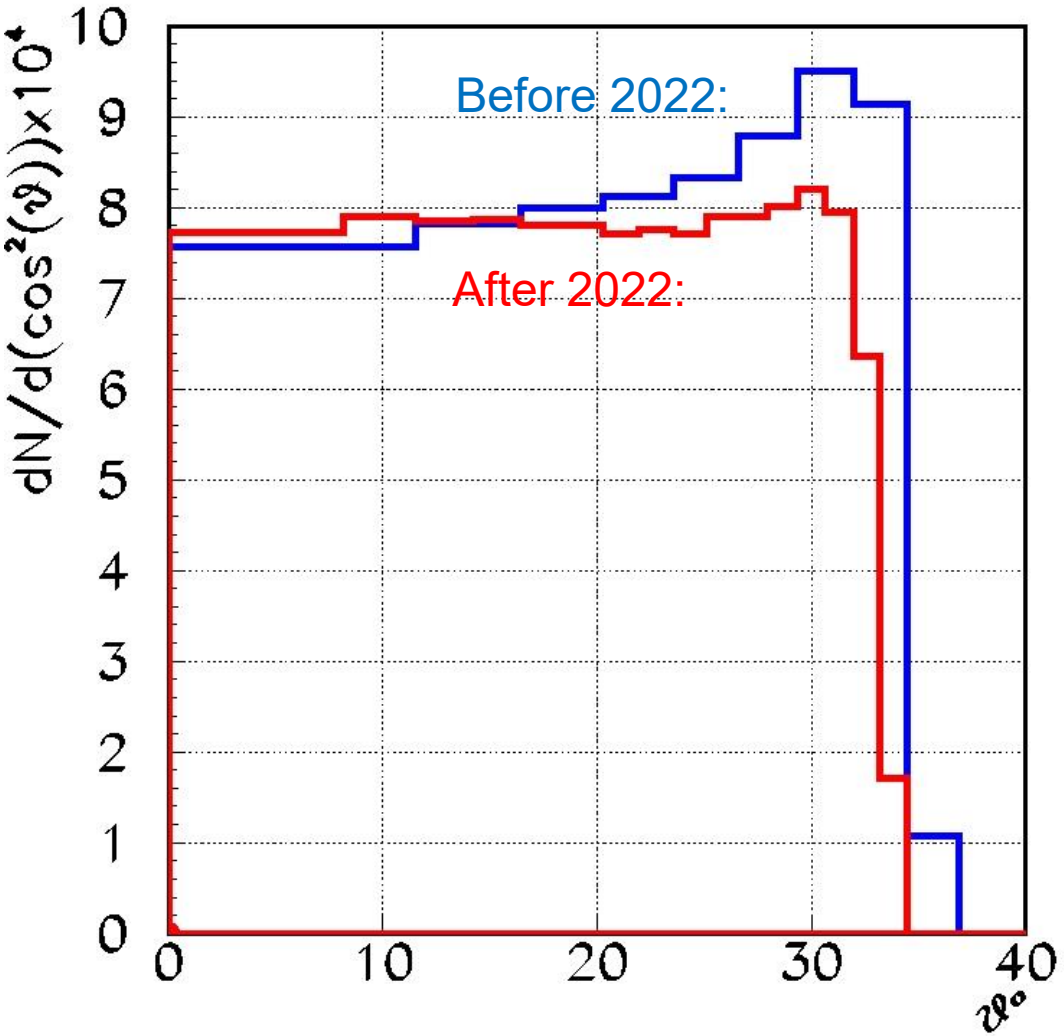
ADF: **$A(R) = A(400)\cdot((R/400+1)/2)^{-bA}$**

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

$b_A > b_Q$

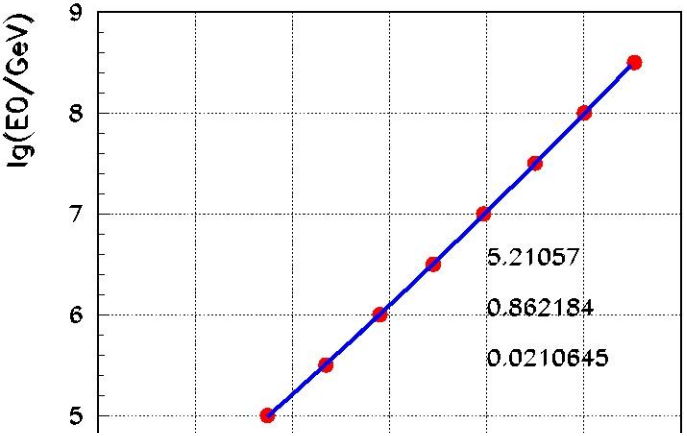
The angular corrections of the experimental Q200 and Q100 and the zenith-angular distribution of EAS.

The direction of all stations to the zenith made it possible to obtain the zenith distribution of the number recorded showers and thus verify the average angular function of the station applied in the processing.
EAS with energy ≥ 1 PeV are used



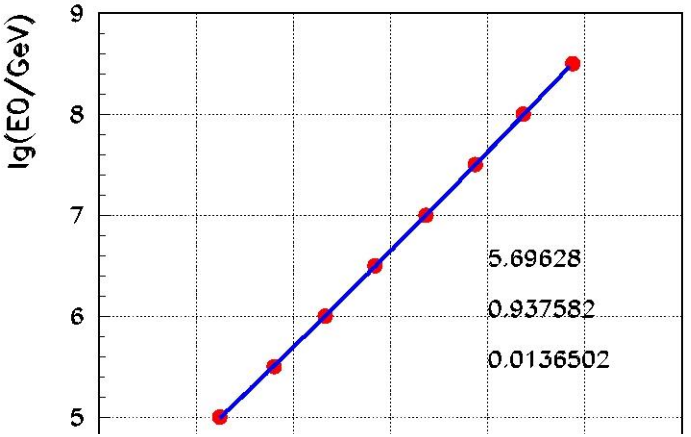
Conversion from Q_R to the primary energy

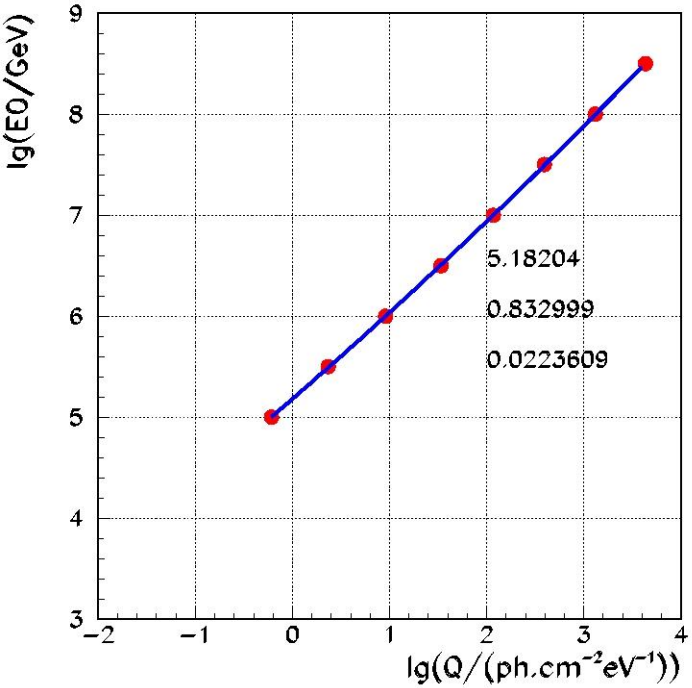
Q_{100}



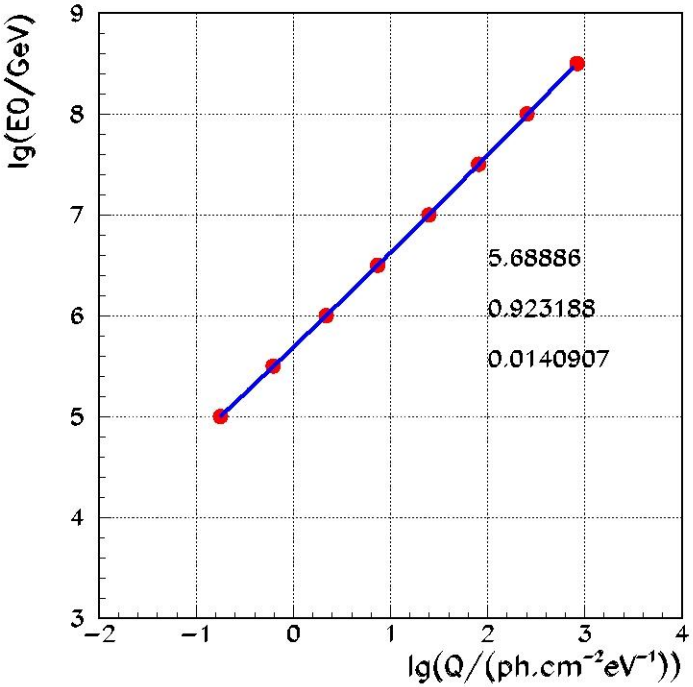
vert. θ≤ 30°

Q_{200}





tilted θ≤ 45°



Conversion from Q_R to primary energy

To determine the energy of the primary particle generating EAS, a recalculation of the Cherenkov light flux density at a distance of R =100 or R=200 m from the shower axis is used. Conversion from the measured $\mathbf{Q_R}$ density to the density in the vertical direction of the Q_R scale(0):

$$\mathbf{lg(Q_R(0)) = lg(Q_R/a\_corr) + (a - b \cdot lgQ_R) \cdot (sec(\theta) - 1)}$$

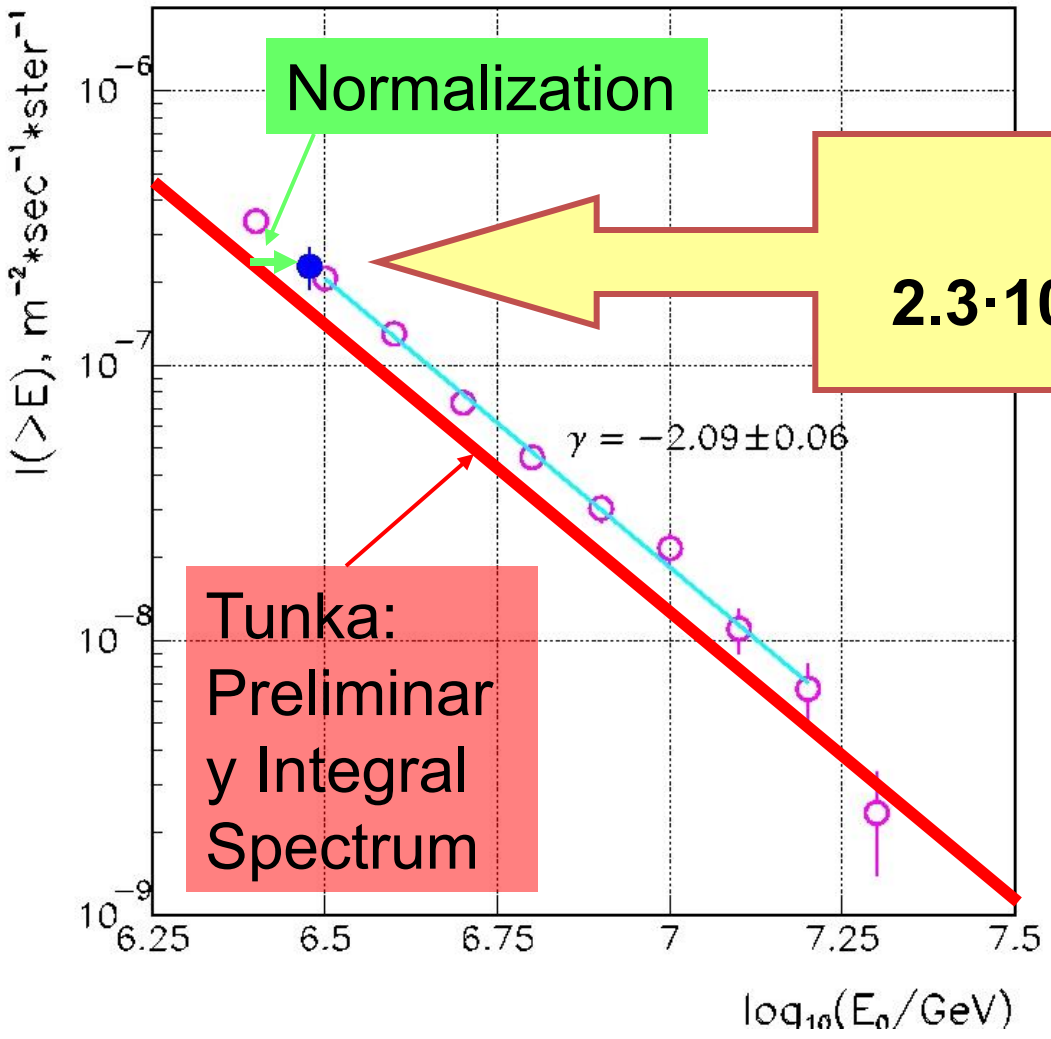
The conversion to the energy of the primary particle E0 is performed using the parabolic formula:

$$\mathbf{lg(E_0/TeV) = A \cdot (lg(Q_R(0)) + B)^2 - C}$$

The constant **C** is adjusted by normalizing the resulting integral spectrum to a known intensity of cosmic rays at an energy of $3 \cdot 10^{15}$ eV. To present all the results obtained in previous measurement seasons, listed in the first paragraph of the report, Data from the 2019-2020, 2020-2021 and 2022-2033 seasons have been re-processed to a single methodology.

	a	b	A	B	C
Q_{100} vertical	1.01	0.233	0.021	20.484	6.55
Q_{100} tilted	1.25	0.077	0.022	18.719	5.59
Q_{200} vertical	0.21	0.138	0.014	34.594	13.44
Q_{200} tited	0.26	0.050	0.014	32.787	12.41

Absolute Energy Calibration



QUEST: Reference Intensity

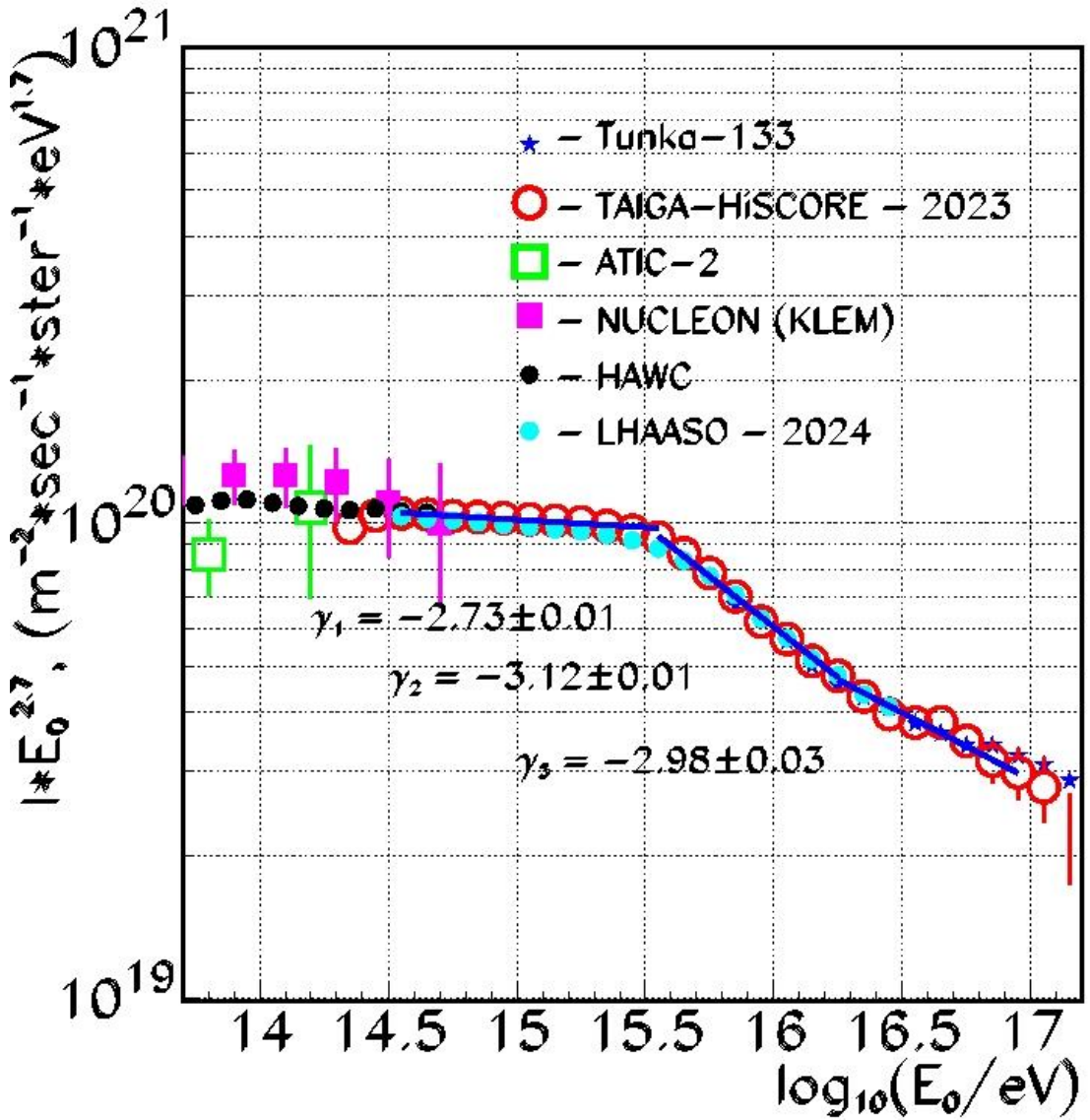
$I(E_0>3\cdot10^{15}$ eV) = $2.3\cdot10^{-7}$ $[m^{-2}\cdot s^{-1}\cdot sr^{-1}]$

This method provides the uncertainty of absolute energy less than 10%.

Experimental energy spectrum for directing stations to Zenith

Statistics: 70 nights, 282 hours
$\theta \leq 30^\circ$
Effective area 1.03 km^2
Solid angle 0.785 sr

7 million EAS
≥ 300 TeV 6.5 million EAS
≥ 3 PeV 0.17 million EAS
Comparison with direct satellite and balloon experiments and HAWC.
The LHAASO experiment uses the classical technique of determining the energy of the EAS by the number of charged particles near the shower maximum with correction by the number of muons.

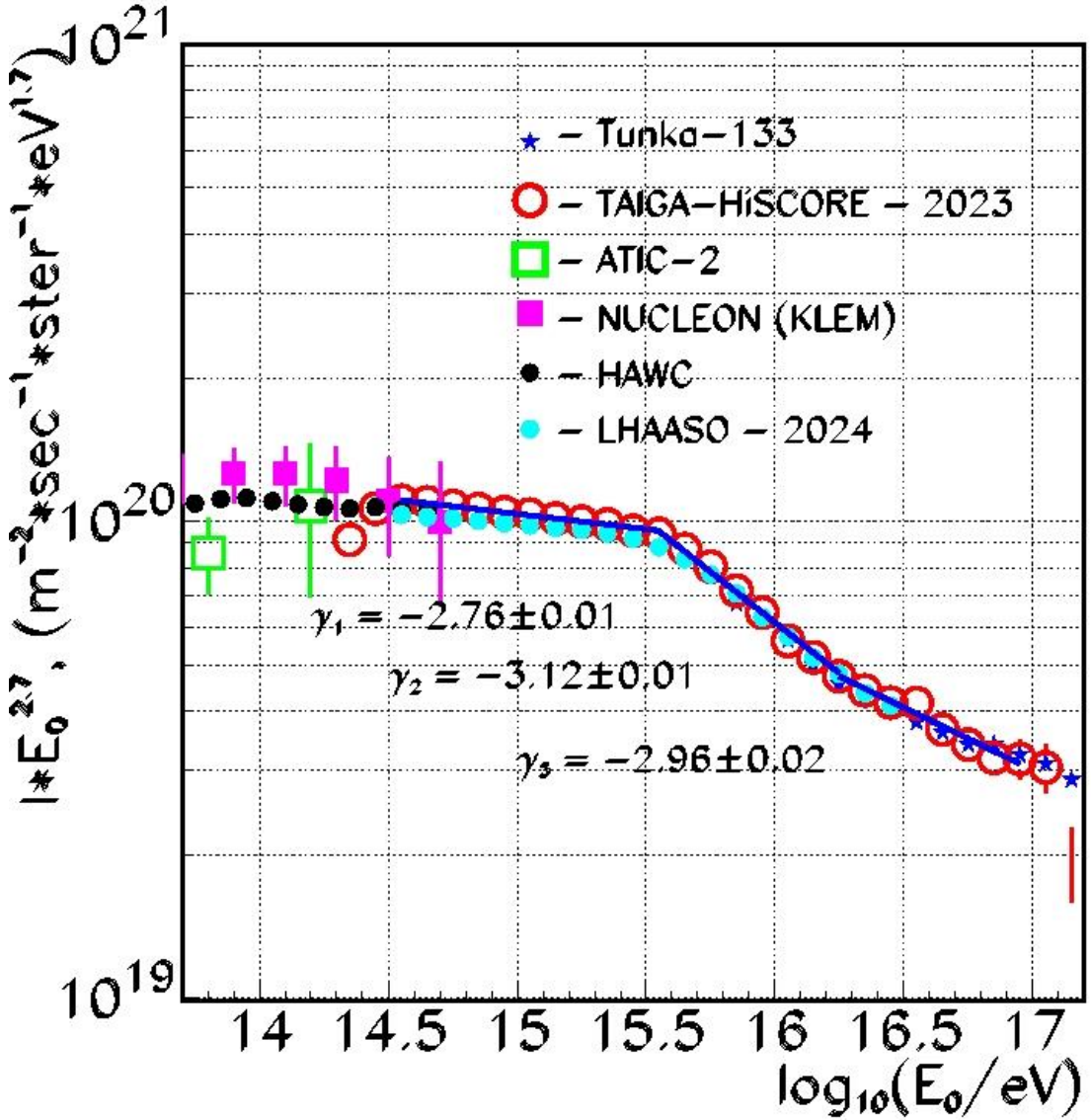


Experimental energy spectrum for directing stations 25° from Zenith

Statistics: 97 nights, 423 hours.
$\theta \leq 45°$
Effective area 1.03 km^2
Solid angle 0.631 sr

≥ 300 TeV 6.5 million EAS
≥ 3 PeV 0.2 million EAS

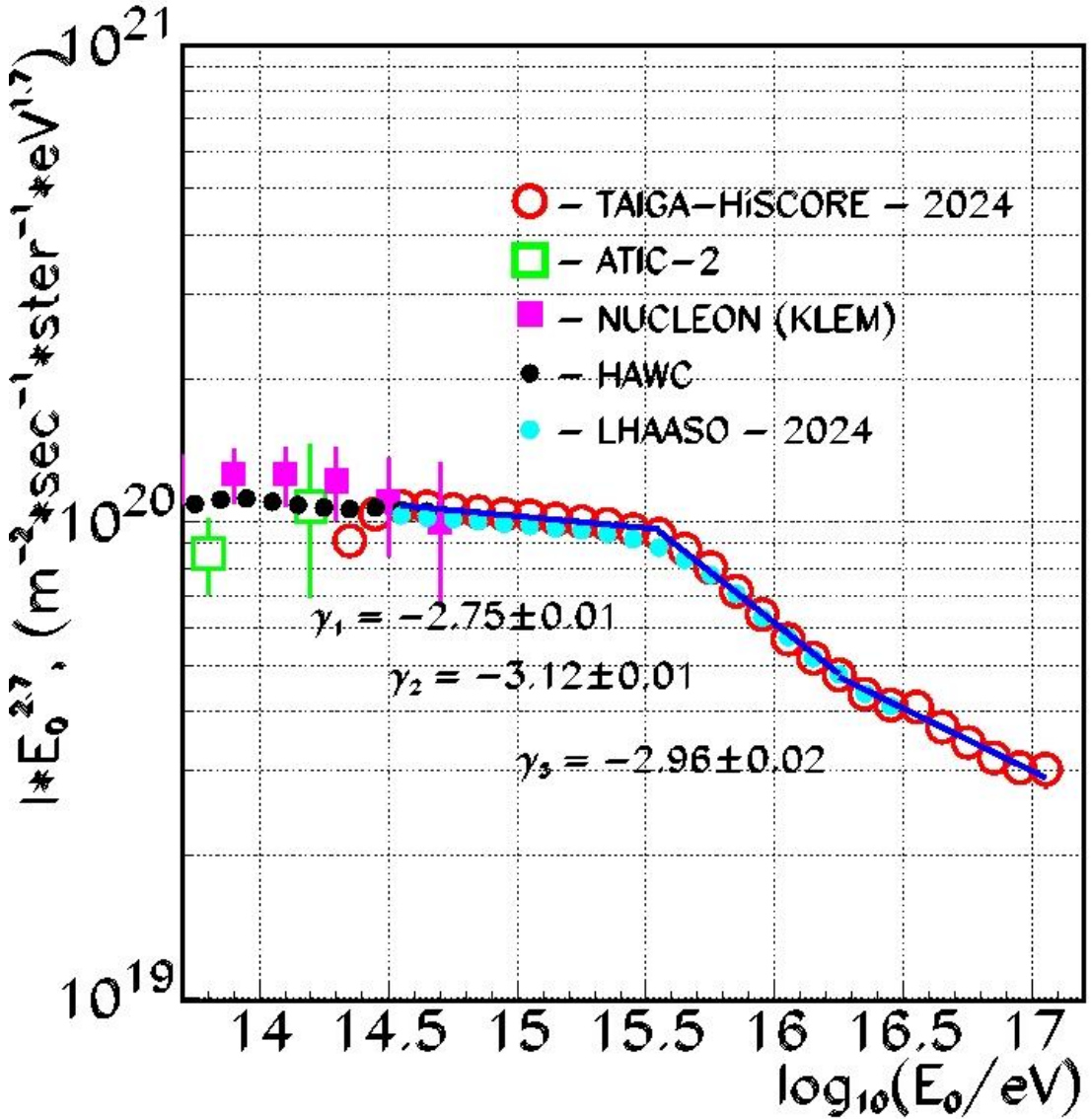
Comparison with the same experiments as at the previous slide.



Energy spectrum for the 3 seasons of observation 2021 – 2024

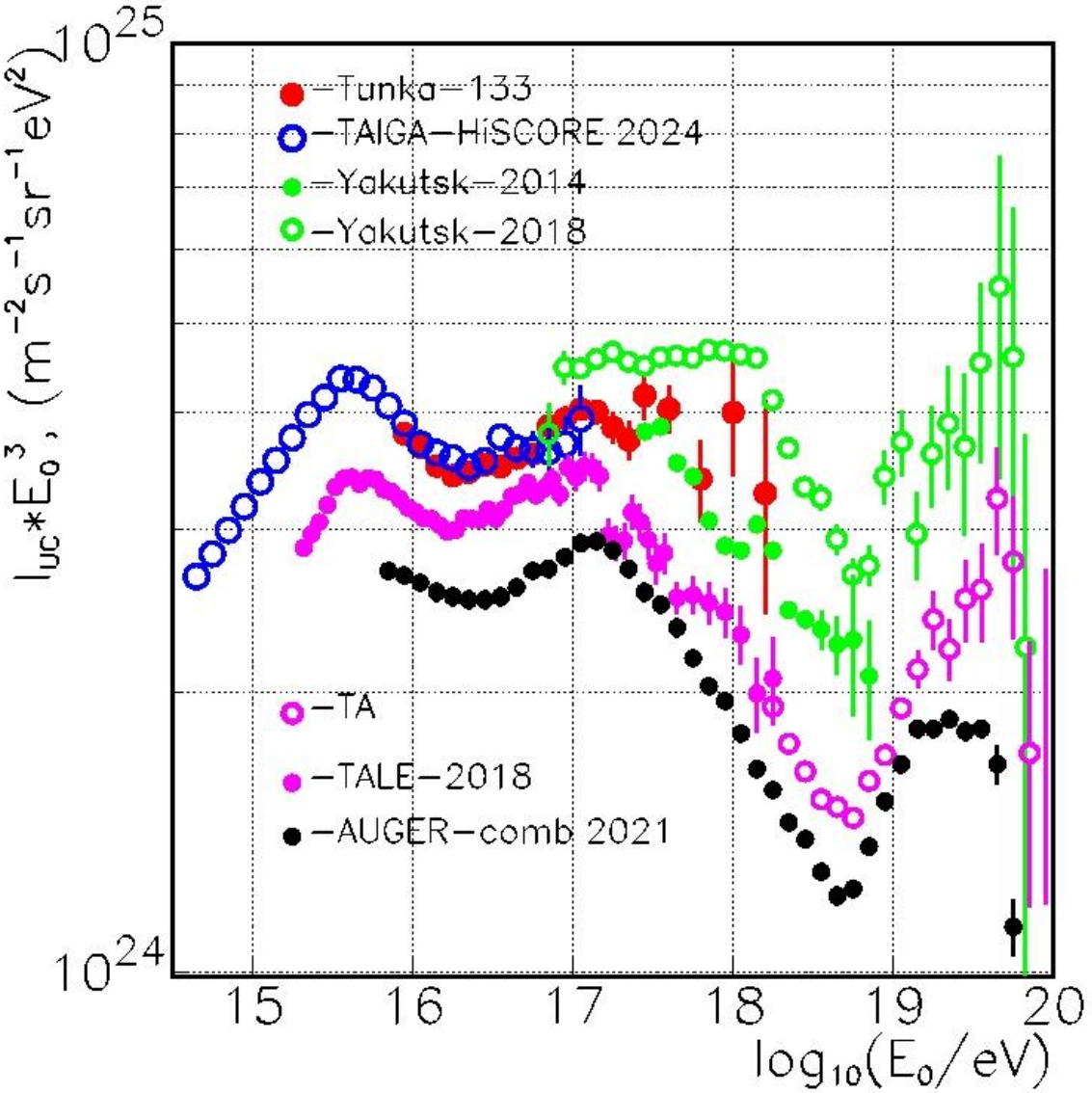
Statistics: 167 nights,
705 hours.
Effective area 1.03 km^2

Combined spectrum using the solid angles as the weights.



Comparison with the Giant Arrays results (what is the energy of the second knee?)

The giant arrays claim two main features of the spectra: the second knee and the ankle,
But they have a little bit different energy calibration:



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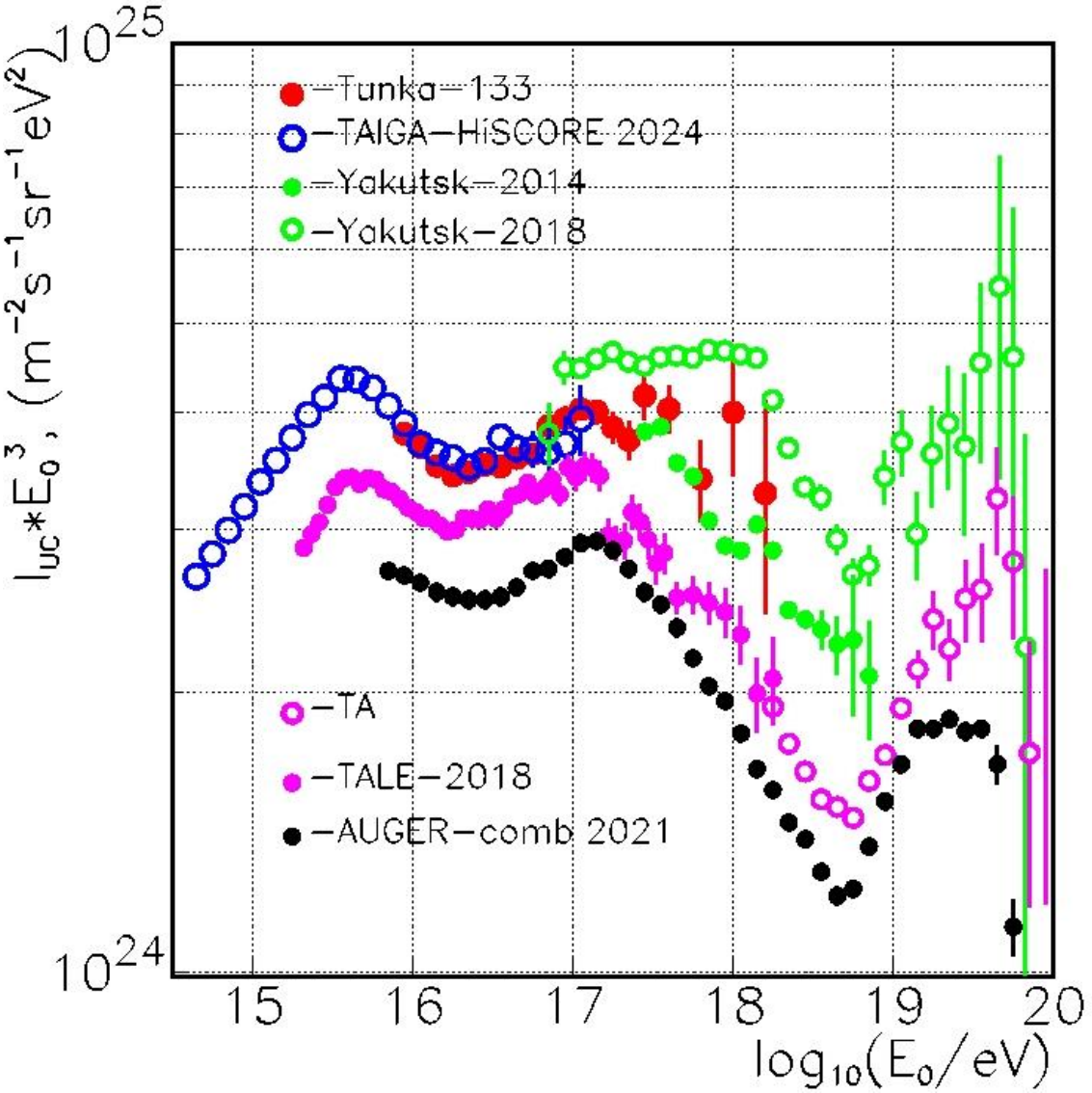
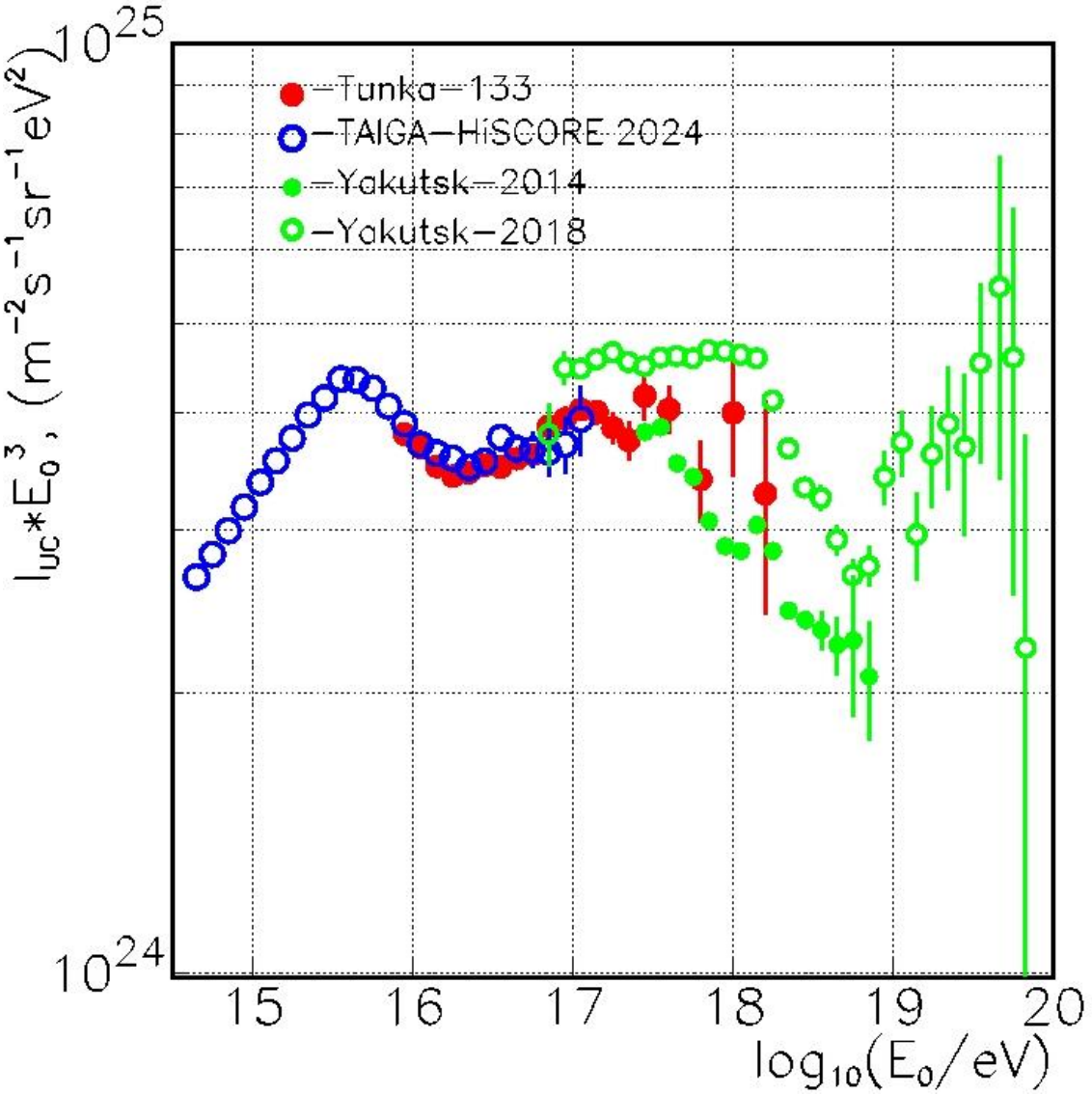


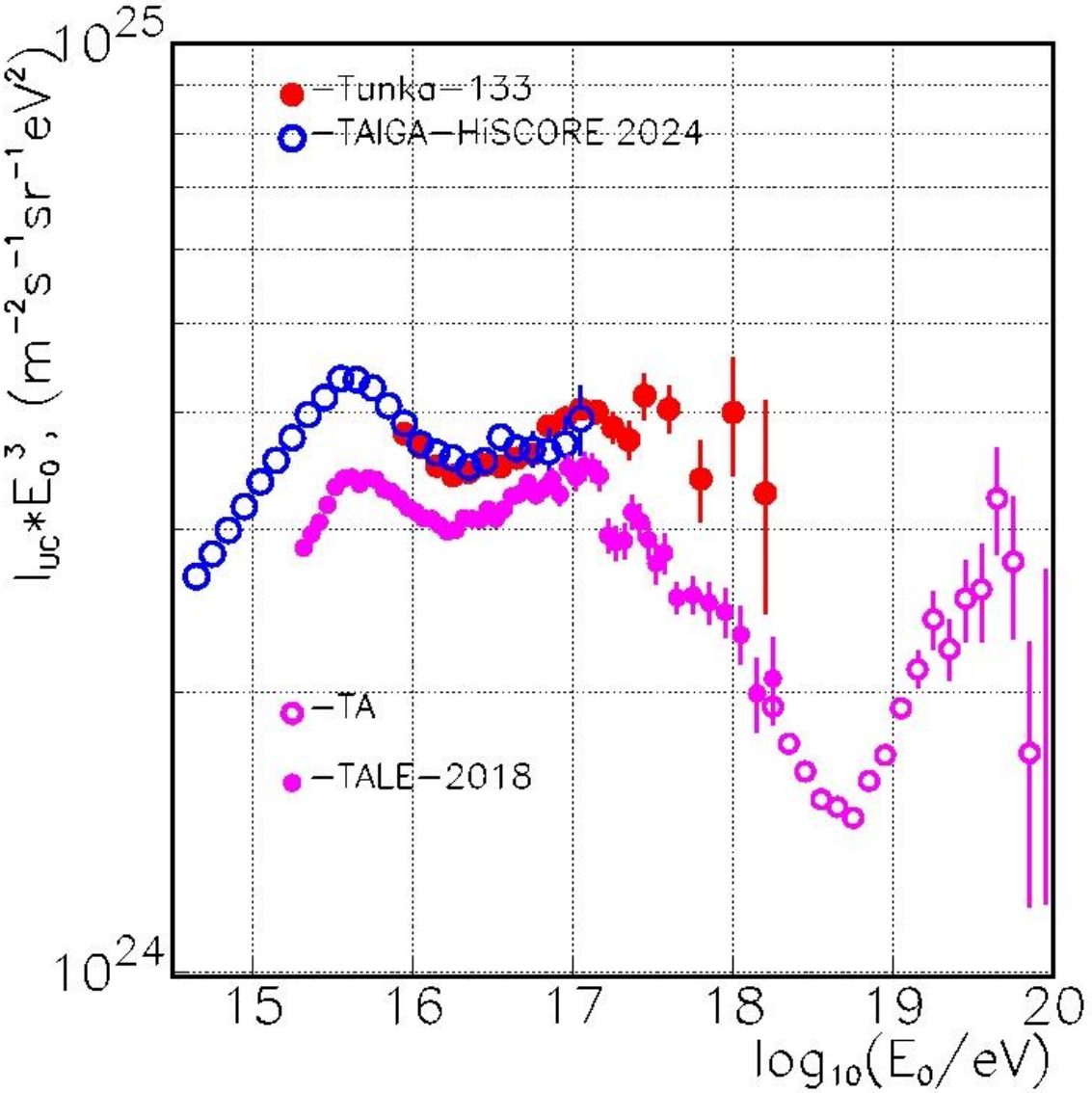
Separate comparison (Yakutsk Array)

Yakutsk Array publications differ for different years 2014 and 2018:

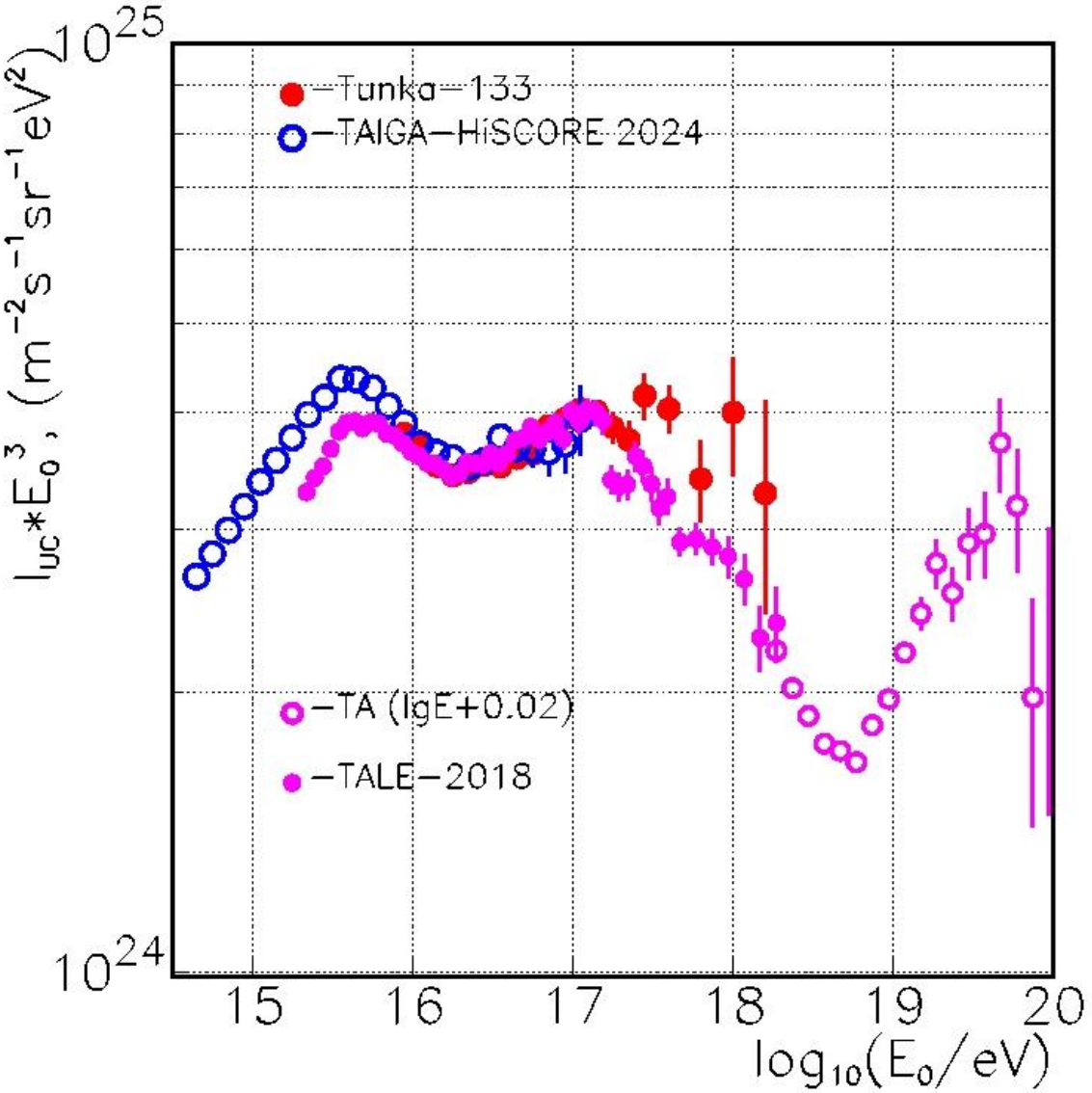


Separate comparison (Telescope Array + TALE)

Combined spectrum



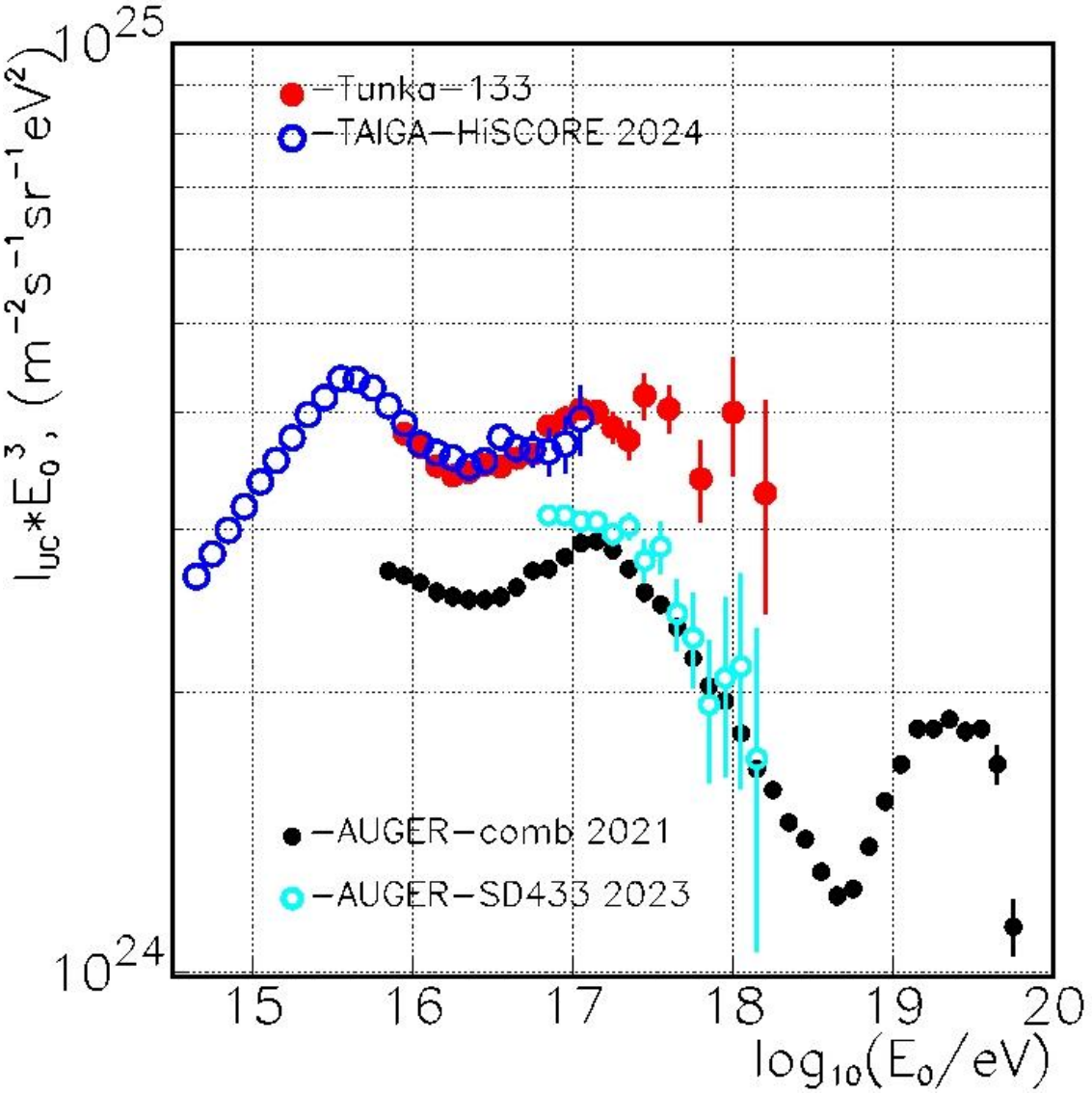
Shift of TA+TALE energy up to 5%



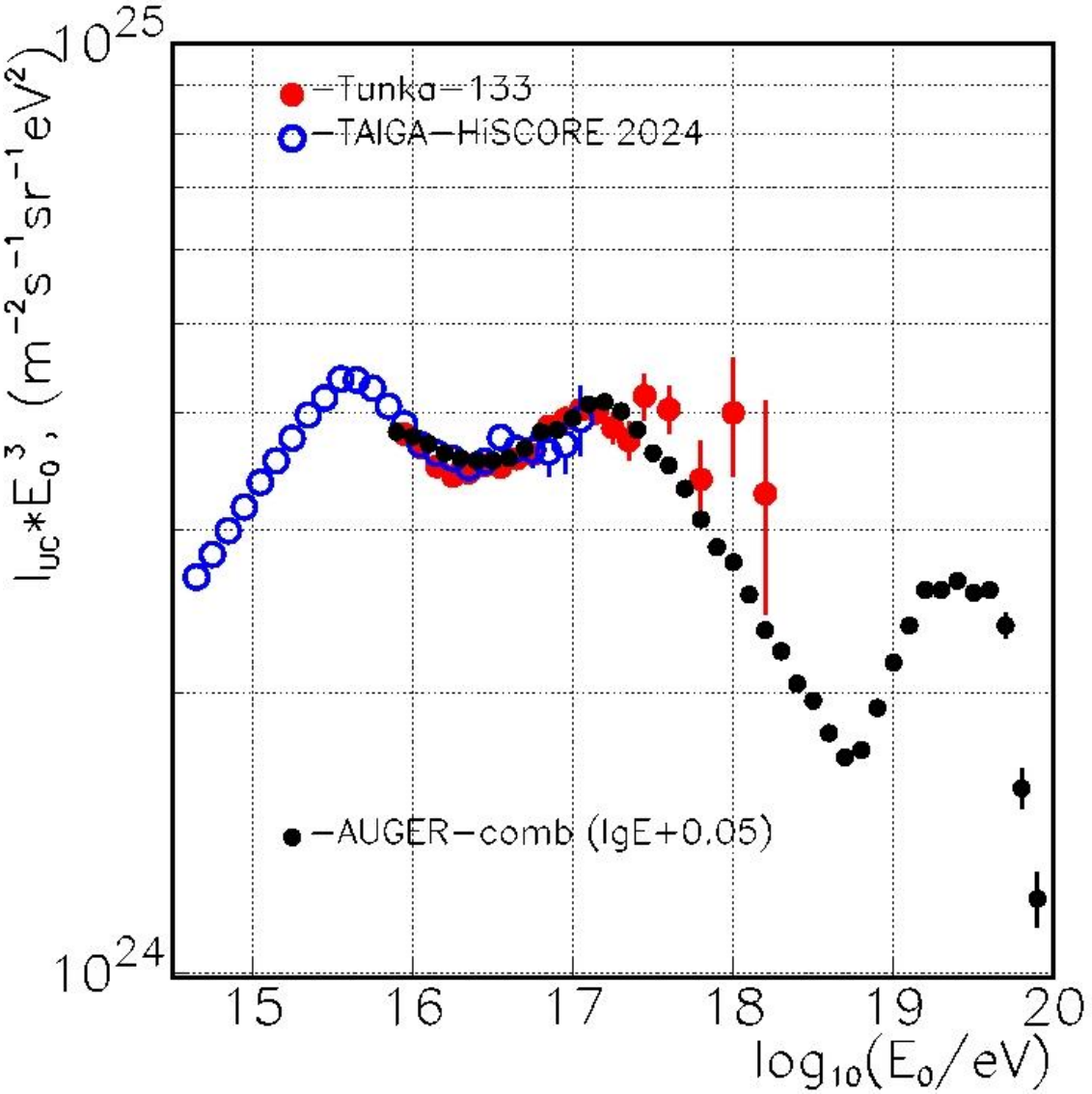
Separate comparison (PAO combined)

Main parts of the Auger combined spectrum:

≤ 100 PeV – Cerenkov light
100 PeV – 1 EeV – SD750
≥ 1 EeV – SD1500



Shift of the Auger combined energy to 12%:



Conclusions

1. All particles energy spectrum in the range 300 TeV – 3 PeV has no any special features – changes of the pawer law index 2.5 ± 0.01.
2. Our pure Cerenkov light spectrum agree with the spectra of direct satellite and balloon experiment as well as the high mounting experiments HAWC and LHAASO.
3. The classic knee at 3 PeV is well confirmed.
4. The first ancle at about 20 PeV is confirmed too.
5. We plan to enlarge the energy range of TAIGA-HiSCORE measurements with the additional low gain detectors and continue analysis of the Tunka-133 array data to reach the proof of the second knee.
6. It seems that the energy calibration of the giant arrays TA and Auger has to be corrected to reach precise agreement in the range 100 TeV – 100 EeV.

Thank you for attention!