Second irregularity on the spectrum of cosmic ray at energies ~10^{17} eV by long-term observations of Small Cherenkov EAS array

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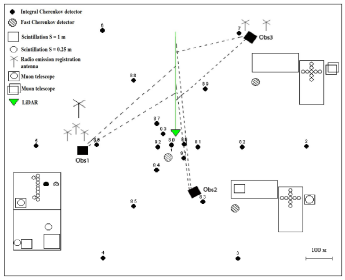
Abstract. The paper presents cosmic ray spectrum by Small Cherenkov Yakutsk array data for 20 continuous years of observation. The spectrum is obtained from Cherenkov light flux – the energy scattered by charged particles of air showers in the atmosphere. It has been shown by measurements that in the cosmic ray spectrum there is a break in the slope at energy ~10^{17} eV. The reliability is based on spectra of other compact array experiments and simulations to check for systematic uncertainties, which could affect the shape of the spectrum. In addition, another confirmation is change in mass composition of cosmic ray obtained from longitudinal development of air showers with energy 10^{16}-10^{18} eV.

Yakutsk Array

Location: *61°42' N, 129°24' E;* Height: *110 m*
Area of the array: *~8 km²*; Energy range: *$10^{15} \le E \le 10^{20}$ eV*
58 stations with 120 scintillation detectors $\varepsilon_{thr} \ge 10$ MeV
Spacing: *500 m*
Yakutsk array measures: charged component; muon component; Cherenkov light. radio emission

Small Cherenkov array

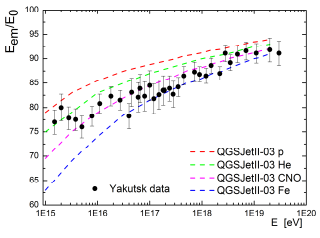


Area of array ~1 km². Spacing 50-250 m, 3 tracking Cherenkov detectors at 250, 300 & 500 m from center.

Accuracy of measurement of EAS characteristics achieved at the Yakutsk

E_0, PeV	σ(R), m	δN_e	σ(Q(100)) phot./m²	σ(Q(200)) phot./m²	σ(Q(400)) phot./m²	$\sigma(\rho_\mu(300))$ 1/m²	$\sigma(\rho_\mu(600))$ 1/m²	θ °, deg
2	9,7	0,15	0,17					1,3
10	7,2	0,11	0,15					1,0
100	15,5	0,27	0,15	0,25				5,7
200	34,6	0,32	0,20	0,20	0,22	0,25		5,4
1000	26,7	0,35	-	-	0,20	0,17	0,19	3,3

To estimate the precision of determining air shower characteristics at the Yakutsk array, full Monte Carlo simulation was carried out. The simulation results are shown in the Table.



Dependence of E_{em}/E_0 on energy

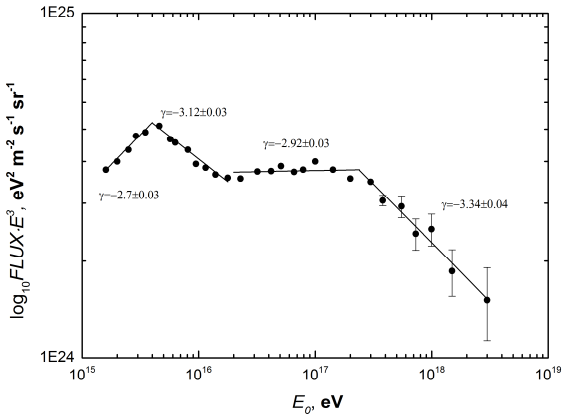
$E_{em} = E_{ei} + E_{el}$

$E_{ei} = k(x, P_\lambda) \cdot \Phi$

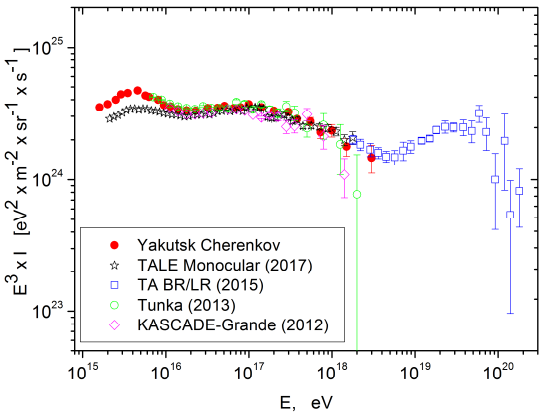
$E_{el} = 2.2 \cdot 10^6 \cdot N_s(X_0) \cdot \lambda_{eff}$

E_{ei} – energy scattered by electrons in the atmosphere above observation level
E_{el} – energy carried by electrons below observation level

Yakutsk array spectrum



Comparison with other experiments



Comparison with other experiments TALE[18], TA BR/LR[19], KASCADE-Grande[8] and Tunka [9]. There is a good agreement of the spectra in the energy range 10^{16}-10^{18} eV. There is also a break in the spectrum at ~10^{17} eV in other experiments as well. The spread in the spectrum is partly due to the different methods of estimating energy at each of the EAS arrays.

Summary

For 20 years of continuous observations at the Yakutsk array, a large data of Cherenkov light in the energy region of 10^{16}-10^{18} eV was collected. This allowed us to obtain the following results: the air shower energy was estimated by the energy balance method of all shower particles and the spectrum of cosmic rays in the energy range 10^{16}-10^{18} eV is obtained. The spectrum has irregularity at the energy of ~ 10^{17} eV. The slope of the spectrum changes from γ_3 = -2.92 to γ_4 = -3.34, everything indicates that at the energy of ~10^{17} eV, the break is associated with astrophysical processes in our galaxy, as well as with extragalactic processes. The "second knee" phenomenon can be explained as transition from galactic to extragalactic cosmic rays.

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