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The Size Spectra of Extensive Air Showers in the "Knee" region Measured by Maket-ANI detector

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The MAKET-ANI detector is operating at altitude 3200 m. at slope of mt. Aragats in Armenia. More than million showers with size greater than 10^5 were registered by the MAKET-ANI detector in 1999-2004. Detector has effectively collected the cores of EAS, initiated by primaries with energies of $5\cdot10^{14}$-$3\cdot10^{17}$ eV. After calculating the detector response function and accounting on the registration efficiency we present the EAS size spectra in 5 azimuth angle intervals. Taking into account reach statistics and high quality of data, it can serve for the estimation of the attenuation lengths and phenomenological characteristics of the strong interaction of primary cosmic rays with atmosphere.

1. Calculation of the detector response function

The description of physical results from MAKET-ANI detector is given in [1-5]. In present report we consider methodological biases influence the accuracy of size spectra – the most important outcome of Extensive Air Shower (EAS) experiments and basis of physical inference on energy spectra and theories of Cosmic Ray (CR) origin and acceleration:

$$\frac{dJ(N_e,\theta)}{dN_e} = \frac{n_i}{dN_e \cdot T \cdot S \cdot d\Omega} \tag{1}$$

where n_i – is the number of shower detected within T time-span in the i^{th} size interval , in the solid angle of $d\Omega = \mathrm{Sin}(\theta)\, d\theta\, d\varphi$, on surface of $S=S_{eff}\,\mathrm{Cos}(\theta)$.

Sources of biases in intensity estimation are the arbitrary binning, according to shower size, age and angle of incidence. The inter-bin migration of observed events was estimated using simple event-generator. We simulate size spectra with constant power index γ = -2.5 in energy range from $N_e^{thr} \geq 3.8\cdot10^4$. The age distribution was taken alike measured one and axes were randomly choused in rectangular area of S_{max} = 40x88 m^2, see Figure 1. The angular distribution follows $\mathrm{Cos}^{\rho}(\theta)$, where $\rho=(X_0/\Lambda)$, X_0 =700 g/cm^2, and Λ =140 g/cm^2. 10^8 events were generated. For each shower with fixed size, age and angles of incidence (input parameters of simulation), the number of shower particles at detector location were determined using Nishimura-Kamata-Greizen (NKG) function (vector $k_i^{\,0}$, i=1, 92). Then the obtained $k_i^{\,0}$ values were distorted according to experimental accuracies and experimental data handling procedures to determine the "experimental" EAS parameters – shower size, age, core position and angle of incidence. Sure the reconstructed parameters did not coincide with input ones. The inter-bin migration of showers was enumerated by the "migration" function $\xi(N_e,\theta,)= n_i/ n_i^{\,0}$, where n_i is a number of showers in particular bin, and $n_i^{\,0}$ - number of showers simulated with input parameters fallen in this bin. To keep the efficiency of registration ($n_i/ n_i^{\,0}$ ratio) higher than 0.95 (see Figure 1), we select appropriate areas of shower collections, so called "belts".In Figure 1 these areas are shown as belt1, belt2, etc, corresponding efficiencies are shown in Figure 2.

We collect showers from the maximal area S_{eff}, providing chosen level of the efficiency (>95%), also we keep condition of maximal allowable distortion of age parameter (<0.02).
To check detector response function obtained with simple model, we used the CORSIKA code [6,7] to simulated events for different nuclei, slope of energy spectra, knee position. Obtained results pointed on model-independence of used detector response function and correct account of experimental distortions – the accuracy of reconstructed spectral index was not worse than 0.01-0.015.

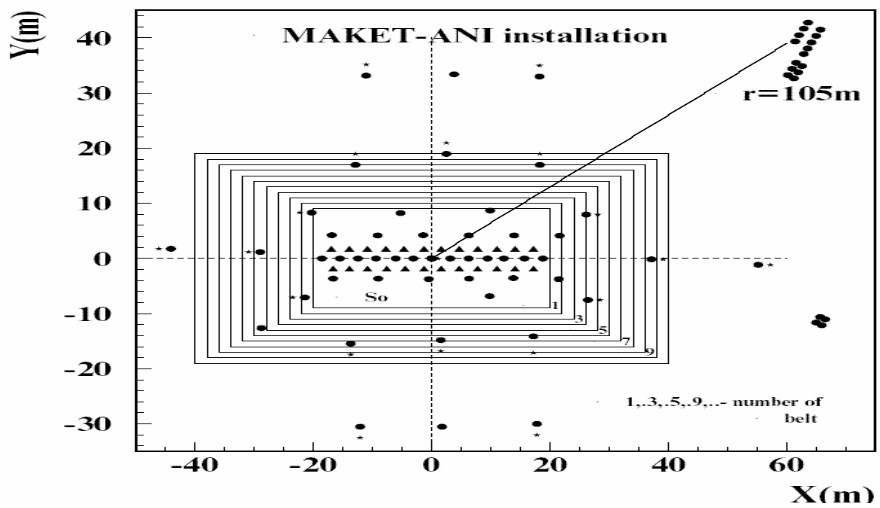

Figure 1.. The MAKET-ANI detector. The nested rectangular surfaces represent shower selection areas

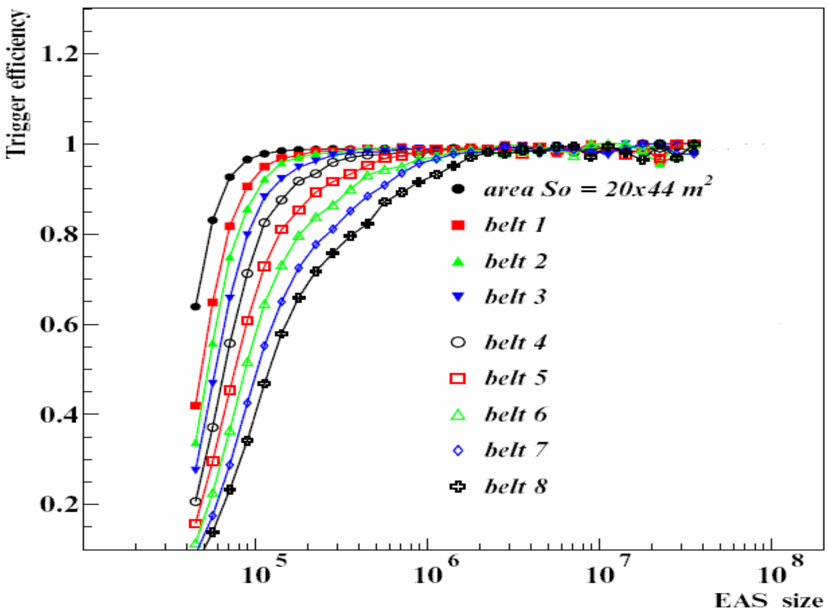

Figure 2 . The efficiency of shower registration, dependent on shower size and collection area

2. The size Spectra

The size spectra, corrected on response function, were approximated by [8]

$$\frac{dJ(N_e,\theta)}{dN_e} = A(\theta)\cdot N_e^{-\gamma}(1+(\frac{N_e}{N_e^{knee}})^{\delta})^{\Delta\gamma/\delta} \quad (2)$$

Here A(θ) - shows angular dependence of spectra , Δγ change of power index γ_1-γ, where γ and γ_1 – spectral indexes before and after the knee, N_e^{knee} - knee position, and δ – the sharpness of the knee.

In the Table 1 are depicted parameters of approximation (2) of the size spectra, measured by MAKET-ANI detector for 5 uniform by Sec(θ) intervals. In Figure 3 the size spectra are presented in the graphic form along with size spectra measured by KASCADE experiment [9].

Table 1. The size spectra measured by Maket-ANI detector.

With response						
$\Delta\theta^o$	γ	Δγ	N_e^{knee}	A	δ	χ^2/ndf
0 - 23.5	2.53±0.002	0.45±0.02	$1.58\cdot10^6\pm8\cdot10^4$	641.9±11	7.1±1.7	1.1/19
23.8-32.4	2.52±0.002	0.43±0.02	$1.33\cdot10^6\pm6\cdot10^4$	333.3±8.5	11.6±3.0	1.9/17
32.4-38.5	2.47±0.003	0.47±0.03	$1.08\cdot10^6\pm8\cdot10^4$	114.4±3.8	3.9±0.8	1.2/19
38.5 - 43	2.45±0.003	0.45±0.03	$0.86\cdot10^6\pm6\cdot10^4$	53.6±2.6	4.4±1.6	0.8/17
43 - 46.8	2.44±0.006	0.48±0.04	$0.70\cdot10^6\pm6\cdot10^4$	29.2±2.2	4.7±1.4	0.9/16

The numbers indicate the effective atmosphere depth, corresponding to different zenith angles of incidence. Knee positions for both Maket-ANI and KASCADE data were calculated by formula (2).

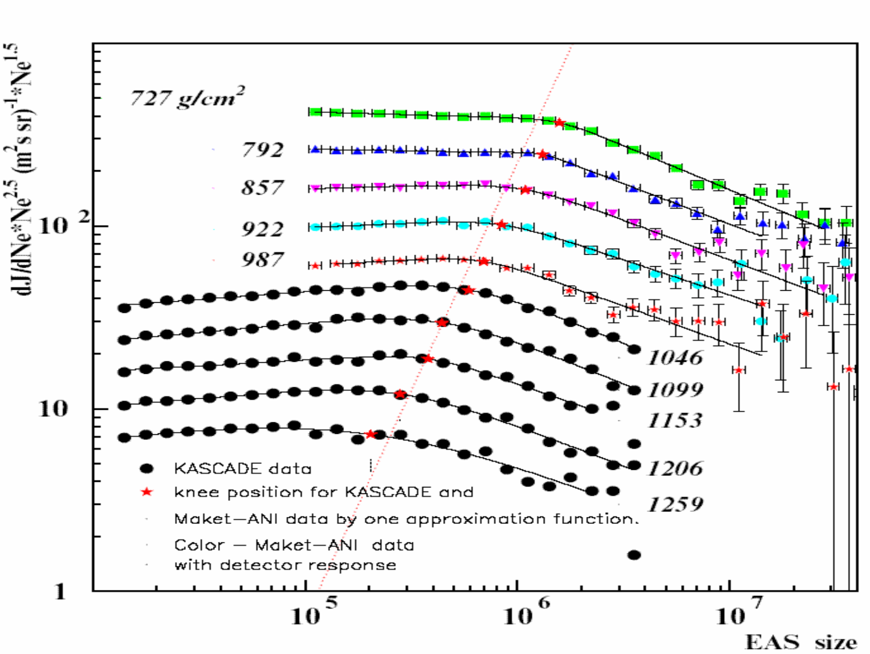

Figure 3. The size spectra of MAKET-ANI and KASCADE [9] experiments

3. Discussion

EAS size spectra at the atmosphere depth of 700 g/cm^2 are presented with great statistics (more than 1.2 $\cdot 10^6$ events). Remarkable coincidence of spectra measured by MAKET and KASCADE detectors and large slant-depth available from joint data give well establishes ground for estimation of attenuation length. Taking into account MAKET results in selection of light and heavy primaries [5] we can pose the problem of estimation of phenomenological parameters of strong interaction of primary nuclei with atmosphere for energies till 10^{16} eV.

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