Monte-Carlo simulation of trigger conditions for Maket-ANI installation

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For calculation of the trigger efficiency and estimation of the accuracy of the EAS parameters reconstruction a simple Monte-Carlo simulation routine was elaborated. The events are simulated, taking into account of EAS fluctuations, detecting system accuracies and trigger condition. For simulated events analysis the same procedures as for experimental ones were applied.

1 Input parameters of simulation

The input parameters of the program are EAS size N_e, age parameter s, shower core position X_0, Y_0 and θ, ϕ angles of incidence . Each of this parameters is simulating using experimentally observed functional form [1-4]: N_e is simulated assuming power law with index $\gamma = 2.5$ and threshold ${N_e}^0 = 3 \cdot 10^4$:

$$F(N_e) = \frac{(\gamma - 1)}{{N_e}^0} \left(\frac{N_e}{{N_e}^0} \right)^{-\gamma}. \tag{1}$$

The EAS core position - (X_0, Y_0) is simulated uniformly on a fixed area.
The angles of incidence are simulated in following way:
azimuthal angle ϕ - from 0^o to 360^o uniformly;
zenith angle θ by $Cos^{\rho}\theta$ in interval from 0^o to 60^o, where $\rho = 700 g/cm^2/\Lambda_{ABS}$, where $\Lambda_{ABS} = 130 g/cm^2$ is showers absorption length [3,4].
The age parameter s is simulated by Gaussian function with mean $< s(N_e, \theta) >$ and variance $\sigma_s =$ 20% of $< s(N_e, \theta) >$ [2]. Dependence of s from N_e and θ is assumed to be:

$$< s(N_e, \theta) >= 1.0611 Sec^{0.25}\theta - 0.11 Lg(N_e/10^5). \tag{2}$$

2 The ADC response simulation

EAS local densities are measure with a scintillation detectors,the light is collected by photo multipliers (PM), the analog signal converted to code by

$$K = D Ln A + C \tag{3}$$

K is the registered code (output of ADC), D is the scale factor (or decrement) of ADC, A - output signal of the PM and C - calibration constant. If C defined as a code (K_0) of mean energy deposit corresponding to the incidence of the vertical single particle, then A is measured in units of particle number. From calibration experiments we obtained D=9.5 [5]. The calibration constant $({K_0}^i)$ for each detector is simulated by Gaussian function with mean $({K_0}^i) = 5.5$ and MSD $\sigma_K = 0.3$. After each of 100 reconstructed events they are renovated.
The scale factor of ADC isn't simulated directly, because in the real experimental situation the background spectra index β_i is used for scale factor correction [6].

First the scale factors D_i is simulated for each detector with mean value 9.5 and MSD $\sigma_D = 0.5$ [5]. The background spectra indexes β_i for detectors are equal to (inverse formula (9) from[5])

$$\beta_0{}^i = 2.5\frac{D_i}{9.5}. \tag{4}$$

After each 8 (as in experiment) cycles of $(K_0{}^i)$ recalculation, the background spectra index β_i are simulated by Gaussian function with mean $\beta_0{}^i$ and dispersion $\sigma = 1\%$ for detectors with $1m^2$ area and $\sigma = 3\%$ for detectors with $0.1m^2$ [5]. Observed particles number in a detectors are reconstructed by

$$n_o{}^i = exp\left(\frac{K^i - K_0{}^i}{\delta_i}\right) \tag{5}$$

$$\delta_i = 2.5\frac{D_i}{\beta_i}, \tag{6}$$

where δ_i have Gaussian distribution with mean D_i and dispersion $\sigma = 1\%$ and 3% accordingly.

3 The array response simulation

Using NKG function for $(N_e, s, X_0, Y_0, \theta, \phi)$ the particles number n^i in each detector is calculated. Obtained densities are distorted accounting to the EAS and detecting system fluctuations. The Puasson form up to $n^i \leq 10$ and Gaussian since $n^i > 10$ with $\sigma = \sqrt{n^i}$ were used. Connection between experimentally observed particles number $n_1{}^i$ and expected n^i is described by a function

$$n_1{}^i = n^i\left(\frac{r_i}{r_m}\right)^\alpha, \tag{7}$$

where $r_m = 118m$ (for the ANI altitude) is the Moliere radius and r_i is the distance between EAS core position and detector.The value of α is distorted by Gaussian with mean 0.18 [6] and MSD $\sigma = 20\%$ The ADC code of each detector is calculated by (3).
Three types of trigger conditions were considered.
A hardware trigger by 11 preselected trigger detectors with the conditions that at least 7 of them are firing with more than $K_{tr} = 18$ code (~ 3.5 particles). The fluctuation of this condition is assumed on a value $K_{tr} = int(18 \pm 1)$ by Gaussian. The efficiency of readout system is ± 1 code in 14% of events. The code of detector saturation is equal 90.
A timing trigger and a software trigger were checked also.
After this check zenith angle - $\tilde{\theta} = \theta \pm (1.13 + 0.00023 \cdot \theta^2)^o$; azimuthal angel $\tilde{\phi} = \phi \pm (64.4/(\theta - 3.16)^o$ were fluctuated by Gaussian [7].

Finally, pseudo experimental EAS event using obtained values of $K^i, K_0{}^i, \beta_i, \tilde{\theta} and \tilde{\phi}$ was reconstructed by the WGAGO program.

The output file contain:

- number of reconstructed event (n_{ev});
- number of all simulated events (n_{tot});
- reconstructed events parameters $(\tilde{N}_e, \tilde{s}, \Delta\tilde{s}, \tilde{X}, \Delta\tilde{X}, \tilde{Y}, \Delta\tilde{Y}, \chi^2, Cos\tilde{\theta}, \tilde{\phi})$;
- simulated events parameters $N_e, s, X_0, Y_0, Cos\theta, \phi$.

4 Results and Conclusion

The Monte-Carlo data bank, simulated under following conditions:

- $\gamma = 2.5$;
- $N_e{}^0 = 3 \cdot 10^4$;
- $abs(X) \leq 60m$;
- $abs(Y) \leq 30m$;
- $\theta \leq 60^o$;
- angular distribution index is $\rho = 700g/sm^2/\Lambda$

was compared with the real experimental data. The comparison between simulated data and experimental flux was made using total number of events:

$$N_{tot} = N_{tot} \int \frac{(\gamma-1)}{N_e{}^0} \left(\frac{N_e}{N_e{}^0}\right)^{-\gamma} dN_e = \int dSd\Omega A(\theta) N_e{}^{-\gamma} dN_e. \quad (8)$$

From (8) we defined $A(\theta)$. In previous papers experimentally observed differential EAS size spectra at different area (as function of EAS size) were presented. The boundaries of area for these spectra were taken from experiment using differential EAS size spectra for different belts. Each belt is defined as $\Delta S_i = S_i - S_{i-1}$,
where $S_i = 4 * (X_0 + i\Delta X) * (Y_0 + i\Delta Y)$
and $Y_0 = 7m, X_0 = 2 * Y_0$;
$\Delta Y = 2m, \Delta X = 2 * \Delta Y$.
The beginning of coordinate system is a center of array. In Fig.1 the differential EAS size spectra for experimentally data and Monte-Carlo simulation for six belts are depicted.

As one can see from Fig.1 starting from $N_e \geq 6{*}10^5$ near 100% efficiency for experimentally data for area $2592m^2$ is provided. Before it the trigger condition influence for different belts were observed. According the definition of different areas as functions of EAS size the differential spectra after applying following restrictions:

- $\tilde{N_e}{}^0 = 5 \cdot 10^4$;
- $0.3 \leq \tilde{s} \leq 1.7$;
- $\Delta\tilde{X}, \Delta\tilde{Y} \leq 4.5m$;
- $\theta \leq 50^o$;

for experimental and simulated data was obtained for six angular intervals with steps $\Delta Sec\theta = (1 - Sec50^o)/6$ and 30 logarithmic uniform intervals of N_e. The efficiency of the trigger condition and EAS parameters reconstruction is

$$\xi_i(N_e, \theta) = \frac{n_i(N_e, \theta)}{n^T{}_i(N_e, \theta)}, \quad (9)$$

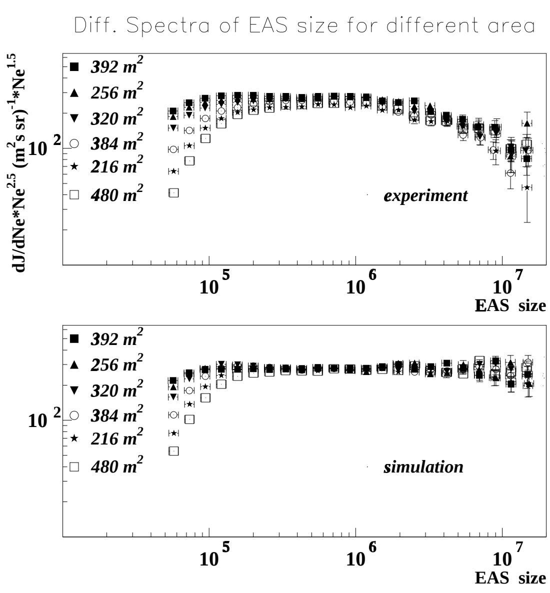

Figure 1: *Experimentally observed differential EAS size spectra and Monte-Carlo simulation data for different* ΔS_i

Table 1: The parameters of experimental spectras approximation by (10

	$\gamma_{sim} = 2.5$		$\gamma_{sim} = 2.4$		$\gamma_{sim} = 2.6$
${N_e}^k$	γ_1	${N_e}^k$	γ_1	${N_e}^k$	γ_1
$1.24 \cdot 10^6$	2.51	$1.2 \cdot 10^6$	2.51	$1.2 \cdot 10^6$	2.51
$1.17 \cdot 10^6$	2.48	$1.10 \cdot 10^6$	2.48	$1.07 \cdot 10^6$	2.47
$0.88 \cdot 10^6$	2.42	$0.86 \cdot 10^6$	2.45	$0.83 \cdot 10^6$	2.44
$0.72 \cdot 10^6$	2.42	$0.73 \cdot 10^6$	2.41	$0.68 \cdot 10^6$	2.41
$0.61 \cdot 10^6$	2.41	$0.57 \cdot 10^6$	2.40	$0.53 \cdot 10^6$	2.37
$0.499 \cdot 10^6$	2.41	$0.503 \cdot 10^6$	2.44	$0.510 \cdot 10^6$	2.40

where $n_i(N_e, \theta)$ is number of reconstructed EAS with observed N_e and θ, ${n^T}_i(N_e, \theta)$ is assumed from power low with index $\gamma = 2.5$ EAS number with N_e and θ. In Fig.2 are presented experimentally observed differential EAS size spectra for six angular intervals corresponding to $N_e \geq 5 \cdot 10^4$. In Fig.3 - 5 experimental data are corrected by efficiency ξ_i. The method was checked for different assumed spectra with different indexes $\gamma = 2.4; 2.5; 2.6$.

In Table 1 the parameters of experimental spectras approximation are presented. The function of approximation [8] is

$$\frac{dJ}{dN_e} = A \cdot {N_e}^{-\gamma} \left(1 + \left(\frac{N_e}{{N_e}^k}\right)^{\alpha}\right)^{\frac{\Delta\gamma}{\alpha}}, \qquad (10)$$

where γ is the spectral index before knee ${N_e}^k$ and $\alpha = 8$ are describing the width of knee region and $\Delta\gamma = 2.9 - \gamma$, where 2.9 is spectral index above knee. As one can seen the results are independent on a small changes of a'priori information about EAS size spectral index.

References

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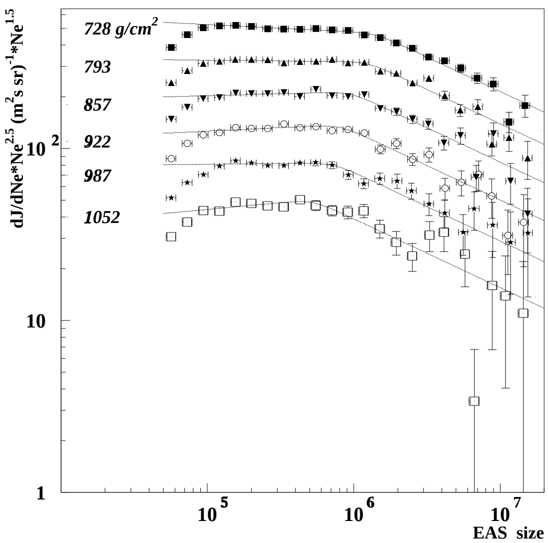

Figure 2: *Experimentally observed differential EAS size spectra without some correction*

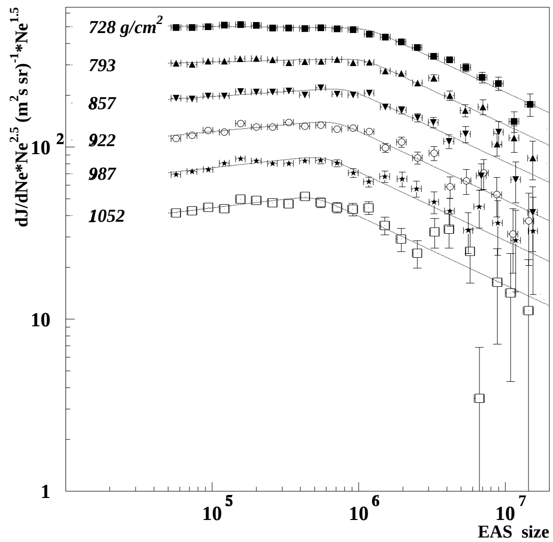

Figure 3: *Differential EAS size spectra after correction (spectral index* $\gamma = 2.5$ *was used in EAS size simulation).*

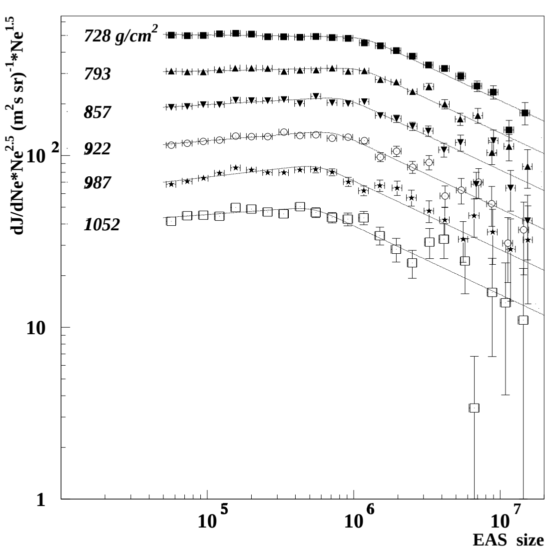

Figure 4: *Differential EAS size spectra after correction (spectral index* $\gamma = 2.4$ *was used in EAS size simulation).*

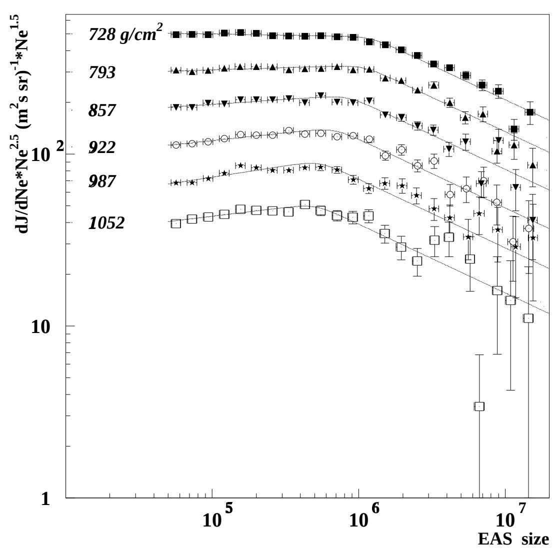

Figure 5: *Differential EAS size spectra after correction (spectral index* $\gamma = 2.6$ *was used in EAS size simulation).*