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Energy Spectrum and Mass Composition at the Knee Energy

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Abstract

We present results of EAS registration by the Lodz extensive air shower (EAS) array. The trigger is the coincidence of at least four scintillation detectors separated by 30 m. The electron and muon ($E > 0.5$ GeV) densities can be estimated from the hodoscopic arrays.

Interpretation of experimental results in terms of the mass composition and energy spectrum of EAS near and above the knee energy will be presented. We made required simulation (based on the CORSIKA results) of EAS development. As the result of simulation we obtained distributions of number of hit hodoscopic units for electron and muon arrays separately and correlations between them. Direct comparison between the data and simulated distributions made with different assumptions about the primary CR energy spectrum and mass composition shows large sensitivity of the method to the models of primary CR spectra.

1 Lodz EAS Array:

Lodz hodoscopic EAS array (Fig.1.) can register electromagnetic and muon component of showers with total number of electrons $\sim 10^5$ - 10^7. The installation detecting electromagnetic component consists of 6 scintillation counters (3 of 0.5 m^2 area and 3 of 1 m^2 area) and 72 Geiger-Müller counters arranged in 4 trays. G-M counters with outer cathode and an effective area of 0.013 m^2 are used in this installation. The 14 m^2 muon detector on the ground can register muons of energy greater than 0.5 GeV. It is built of 104 boxes of 5 G-M counters. The effective area of one box equals 0.136 m^2. The muon detector is shielded from above by 12 cm of iron and 30 cm of lead, and from the bottom by 1 cm of iron and 5 cm of lead.

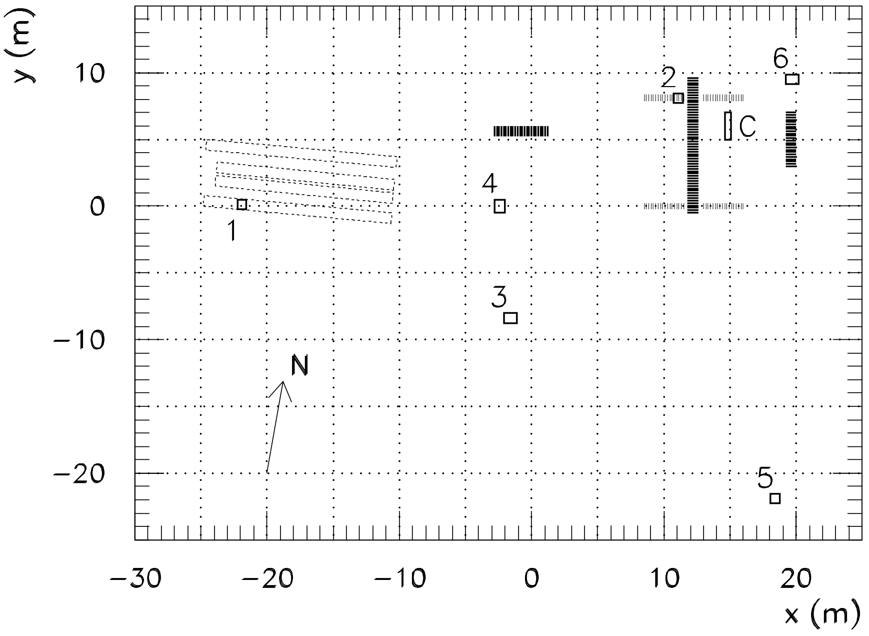

Figure 1: Lodz hodoscopic EAS array. The scintillation counters are numbered. G-M counters for muons above 0.5 GeV are shown as thick black lines. The trays of electron G-M tubes are presented as 4 shaded strips. The underground muon detector is marked by the broken lines.

(The underground muon detector of 42 m^2 area, which can detect muons of energy above 5 GeV does not go into present experimental setup, but will be joined to it in the future).

The array is triggered by the coincidence of four scintillators: 1,2,4 and 5. The amplitudes of signals from each scintillator have to exceed $\sim$ 50 mV (1 particle $\sim$ 200 mV), with time difference between the first and the last signal smaller than $\sim$ 600 ns. When such coincidence occurs following data are registered:

- time of event with accuracy better than 1 s,
- amplitudes of signal from 6 scintillation counters,
- relative times of registrations in scintillators 1,2,4 and 5 with accuracy of several nanoseconds,
- state of hit electron G-M counters (72 channels),
- state of hit muon G-M counters (threshold 0.5 GeV, 104 channels).

We have analized data gathered in the period from 7 July 1997 up to 26 January 1998 (90470 registered EAS). The number of coincidences in one hour was equal to 39.0 ± 7.3.

2 Method of Data Analysis:

The Lodz hodoscope is rather small array as compared to presently built EAS registration systems. Its size does not allow for localization of EAS core and evaluation of total number of electrons and muons for each individual shower. What is more, the total number of electrons and (to a bit smaller extent) also the total number of muons on an observation level show very large fluctuations. Therefore it is not easy (if at all possible) to determine the mass and energy of primary particle which initiated a shower basing on the size of registered EAS.

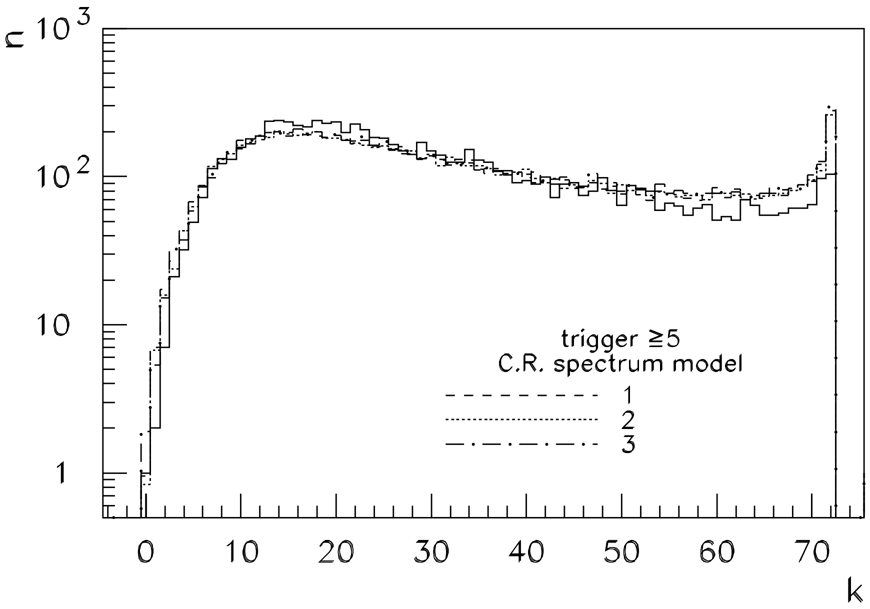

Figure 2: Observed (solid line) and simulated distributions of number of hit electron G-M counters for the level of coincidence min. 5 particles in coincidence scintillators. Normalization for the range k = 30 – 50. Models of CR spectra (1,2 and 3) are described in the text.

To analyze results of our measurements we applied another method of data interpretation. We compared observed and simulated distributions of different registered EAS characteristics and correlations between them obtained for large samples of EAS. Basing on simulations of EAS development in the atmosphere and detector response we can study the influence of entrance parameters (e.g. energy spectrum and mass composition of primary cosmic rays) on the distributions of EAS characteristics on the observation level.

3 Simulations:

We have simulated showers in 4 primary particle energy ranges: $10^{4.4-5.5}$, $10^{5.5-6.0}$, $10^{6.0-7.0}$ and

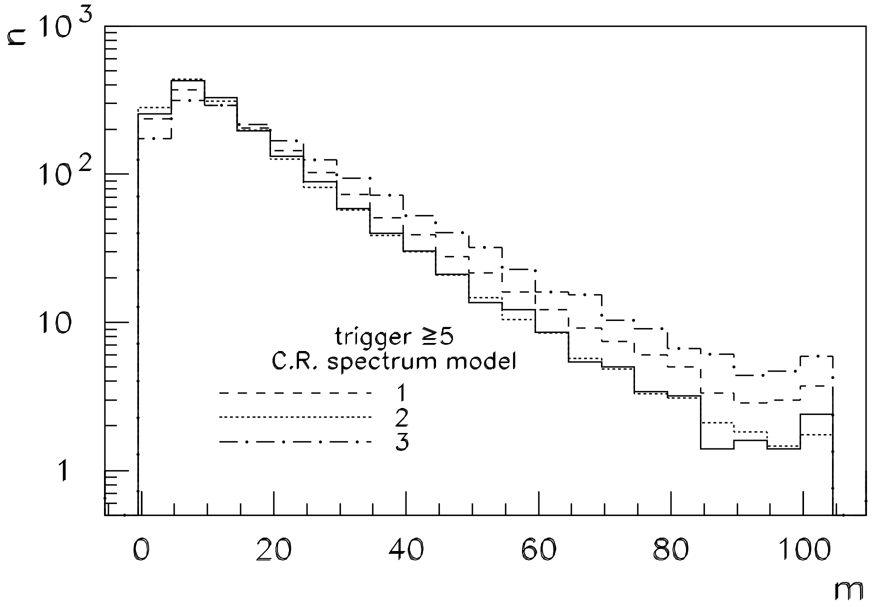

Figure 3: Distribution of number of hit muon G-M counters for the coincidence level min. 5 particles. Experimental results are shown as the solid line. Broken lines represent predicted distributions obtained for different models of CR spectra (1, 2 and 3) described in the text. Normalization as follows from Fig. 2.

above $10^{7.0}$ GeV. For each energy range (and for each set of parameters determining CR energy spectrum and mass composition, and also physical properties of EAS) we simulated the response of our array for $5 \cdot 10^6$ EAS (for highest energies 10^6). To shorten the effective time of simulations we have built an EAS generator which gives EAS parameters on the observation level for given primary particle mass and energy. The generator has been made basing on the results of full simulations of EAS development in the atmosphere performed for several energies (up to 10^7 GeV) obtained from the CORSIKA program v. 520 (Heck et al., 1998). Fluctuations of EAS characteristics on the observation level and correlations between different parameters have been taken into account. The results obtained using our generator are consistent with those obtained using the CORSIKA code.

4 Interpretation of Experimental Results:

The procedure of comparison between experimental and simulated events was following:

1. Simulated distributions of number of hit electron counters k have been normalized to the experimental histograms for chosen coincidence level. Presented results (Fig. 2.) have been normalized in the range k = 30 – 50.
2. Simulated distributions of number of hit muon G-M counters m have been compared to the experimental ones assuming the same coincidence level and the normalizing factor described above (Fig. 3.).

4.1 Comparison of Simulated and Experimental Results for Different Models of Primary CR Mass Composition and Energy Spectrum:

We have made our analysis for 3 different models of primary CR mass composition and energy spectrum:

1. The spectrum with change of spectral slope at the constant energy per nucleon ($1.5 \cdot 10^6$ GeV) for each component. In this model all components have similar intensities for very high energies.
2. The spectrum with the change of slope at constant energy per nucleus equal to $1.5 \cdot 10^6$ GeV. In this case the relative mass composition is constant.
3. The spectrum with the proton component changing its slope at comparatively low energy. Other components are described as in the spectrum 1.

As can be seen from Fig. 3. the simulated distribution of number of hit muon counters is consistent with measurements only for spectrum no 2. The model with rapidly decreasing contribution of protons in the CR spectrum (no 3.) is apparently contradictory with experiment.

4.2 Comparison of Experimental Results and Predictions Obtained for Different Physical Parameters of EAS: In EAS development simulations with the CORSIKA program different models of high energy interactions can be applied. Different models lead to different EAS descriptions on the observation level. The mean numbers of electrons N_e and muons N_μ obtained for the same primary particle energy and mass can differ by the factor of 3 (Knapp, Hech & Schatz, 1996). Our method of analysis is sensitive to much smaller changes of N_e and N_μ. The models A, B and C (Fig. 4) differ only by an additional factor introduced to increase or decrease N_e and N_μ obtained in our generator as compared to the values simulated using CORSIKA code with HDPM model. The differences of N_e and N_μ are of the order of 20%. As can be seen from Fig. 4. such small changes in N_e and N_μ lead to apparent differences in predicted distributions of number of hit muon G-M counters.

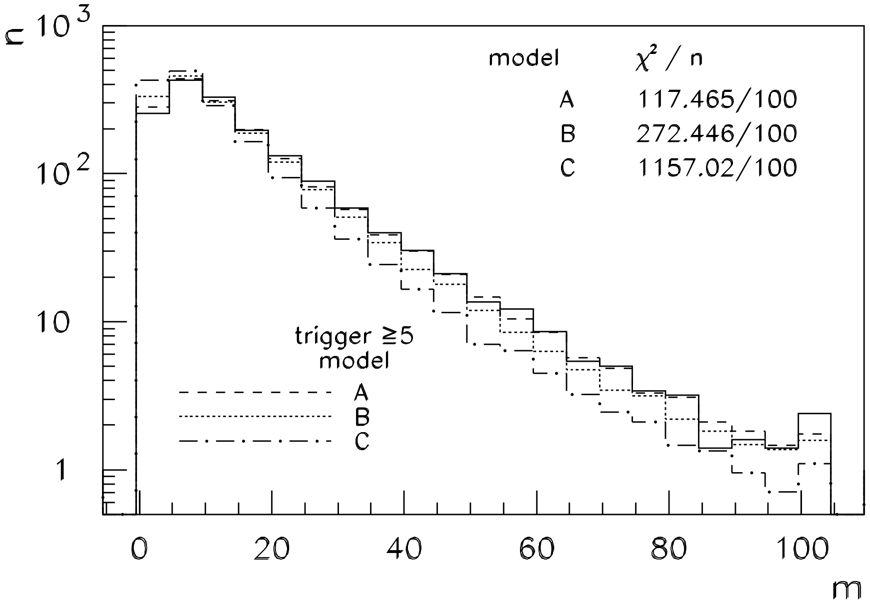

Figure 4: Distributions of number of hit muon G-M counters simulated for different models describing $N_e(E_{cr})$ and $N_\mu(E_{cr})$. CR spectrum with the change of slope at constant energy per nucleus has been assumed. Differences between models are described in the text.

5 Conclusions:

Statistical analysis of data from Lodz hodoscope allows for studies of CR mass composition at the knee energy. Basing on comparison of measured and simulated distributions of number of hit G-M counters we can eliminate some models of CR mass composition and energy spectra. We can also study EAS description parameters and put some constrains on the models of high energy interactions used in CORSIKA code.

References

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