Measurements of EAS particles central density using Baksan array

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***Abstract*. In this study we measured a spectrum of Extensive Air Shower (EAS) particles central density by using the large continuous area of Baksan Carpet array in a wide and the most interesting range from $\sim$10^2 to $\sim$10^5 particles per 200 m^2 or $\sim$ 0.5÷500 m^{-2}. A renovation of data acquisition system has been done for this purpose. After recalculation to EAS size spectrum using Monte-Carlo simulations based on CORSIKA code, it is shown that EAS size spectrum have two knees: proton one at $\sim$10^5 and iron one at $\sim$10$^{6.4}$. Simulations made for pure power law primary spectrum gave similar results thus confirming that EAS structure changes at energy of $\sim$100 TeV/nucleon.**

***Keywords*: EAS, thermal neutrons, hadrons**

I. Introduction

In our previous work on this subject [1] we reported the experimental results showing an existence of the knee in the EAS central density spectrum measured by the Baksan Carpet-2 EAS array at 1700 m a. s. l. The position of the knee was found to be close to $\sim$ 500 particles per 200 m^2 of the Carpet area. This density being recalculated to the EAS size, corresponds to $\sim$10^5 or $\sim$100 TeV of primary energy (it depends on the hadronic mean free path length and on the Earth atmosphere thickness). It has been also shown that change of the spectrum slope occurs at a point where hadrons begin to reach the observational level. Similar spectrum behaviour is expected in the frames of approach developed in [2], [3]. Its origin is connected with a break of the equilibrium between EAS components at the moment when the number of cascading high energy hadron becomes close to 1 or 0. This occurs at primary energy of $\sim$100 TeV/nucleon and it results in a visible knee in EAS electromagnetic components size spectrum even when the primary spectrum follows pure power law. Due to exisence of a spread in primary particle masses from A = 1 to A = 56 (from proton to iron) the visible knee is splitted in to knees: first, proton one at $E_0 \approx$100 TeV and second, iron one at energy $E_0 \approx 100\times56 \approx 5000$ TeV. The latter knee is what people usually call as the knee. To observe the first one, experimenters should have an energy threshold of thier array much less than 100 TeV. That is why so few experiments saw this first knee (see for example [4]). Unfortunatly, in our previous work we had rather narrow dynamic range for energy deposit measuremnts. Some renovations of the data acquisition system have been done and now it's wide enough.

II. Experiment

The experiment is running at Carpet-2 Baksan air shower array at altitude 1700 m a. s. l. The main feature of the array is its large 200 m^2 continuous central Carpet of 400 thick liquid scintillator detectors. After recent modernization [5] we are able to record energy deposit in this central detectors in a very wide dynamic range. The 5th dynod signals from all 400 detectors PMTs are summarized and are digitized by 4 linear ADCs with different gains on inputs. Signals from 5th dynods of our 12-dynods PMT tubes are so weak that we can not measure single particle signal (anode signals are used for this purpose) but, starting from $\sim$100 particles per Carpet it is possible. The anode signals are used for calibration and for trigger production to start measurements: a usual EAS trigger is produced by 5-fold coincidence of Carpet with 4 outer detectors of 9 m^2 sutuated 30 m apart the center, if the signals exceed 1 rel. particle level. The trigger attracts the EAS cores to the center and that is why in this particular experiment we does not locate EAS axis. It is assumed that the Carpet records mostly the central density. We simply accumulate energy deposits in the Carpet if the system is triggered. The trigger counting rate is $\approx$1.5 s^{-1}.

III. Simulations

Simulation were performed using CORSIKA (ver. 6.501, HDPM and GHEISHA models). Primary energy spectrum supposed to follow pure power law with integral index equal to -1.7. In this study we simulated central particle density spectrum in Carpet in case of pure proton primaries. To cover a wide range of experimental energy deposits one should use very wide range of primary energy. In our case the calculations were performed from E_0=100 GeV to E_0=20 PeV. The difference in event intensity at the left and right edge energy is as high as 4×10^{11}! Clear it is impossible to accumulate such a huge ammount of events. Therefore, the full database where splitted in decades: 0.1÷1 TeV; 1÷10 Tev; etc. In each decade as much as possible events were accumulated. Then decade by decade of the artificial showers were applied to the experimental array. Results were summarized with corresponding weights to obtain the total spectrum to be compared with obsevations. Another sets of simulations has been done to calibrate the method and to recalculate the Carpet energy deposit to N_e or/and to primary energy.

IV. Results

Preliminary results of the measurements were obtain after half a year run of the array. The results are shown in Fig. 1, where observed spectrum of energy deposits (ε) in the large central detector (Carpet) is shown. To emphasize the spectrum slope (β) changes we multiplied it by $\varepsilon^{1.35}$. The spectrum reveals exisence of two "knees". The first one ($\Delta\beta$ $\approx$0.33) can be seen at ε_1 $\approx$500 relativistic particles per 200 m^2 and this coincides with our previous measuremnts [1]. The second "knee" ($\Delta\beta$ $\approx$0.40) is seen at ε_2 $\approx$1.2$\times$10^4 relativistic particles and this is what one could expect for "iron knee" position. This "knee" was not seen in our previous measuremnts when signals from PMT's anodes were summarized, due to PMT anodes saturation. The spectrum is shown "as it is" without any corrections. It could be seen that the difference between the "knees" is equal to $\varepsilon_2/\varepsilon_1$ $\approx$24 and this value is 2 times lower than we expected. But, looking more carefully to the graph one could see the difference in the sharpness of the "knees". The "iron knee" must be sharp due to low fluctuations of the iron originated EAS. This also explains small distance between the knees: in case of wider transition region of the right knee the straight lines would cross at higher ε.

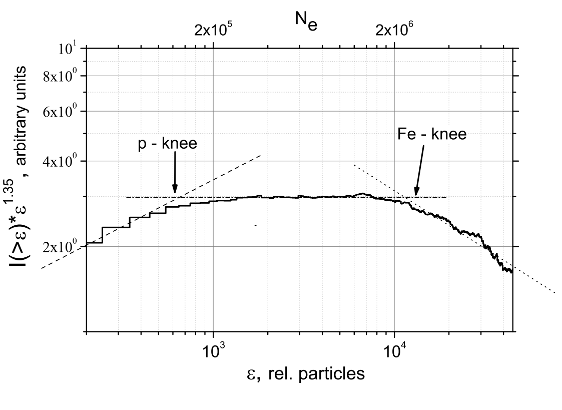

Fig. 1: Measured energy deposit spectrum.

Simulated spectrum is shown in Fig. 2. The simulations were made with the same trigger conditions as they are in the experiment. The roof above the detectors were taken into account. EAS axes were spreaded within 100 m around the Carpet center. It differs from the experimental spectrum because the primary mass composition is very simple here: it contains only protons. Therefore, it must have only "proton knee". Just what we see.

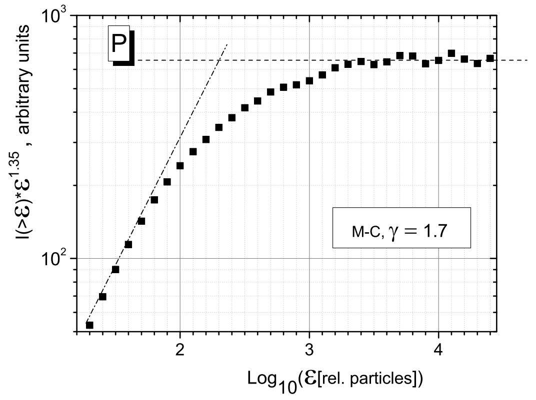

Fig. 2: Energy deposit spectrum simulated with CORSIKA.

V. Conclusion

We have measured the EAS particle central density spectrum in Baksan Carpet array in the range of $\sim$ 0.5$\div$500 m^{-2}. The spectrum reveals two breaks in the quasi-power law spectrum: the first one at 2.5 m^{-2} associated with proton pimaries and the second one at 60 m^{-2}, associated with iron primaries and coinciding with what is known as the "knee". The results of the CORSIKA based Monte-Carlo simulations made for pure proton composition and for pure power law primary cosmic ray spectrum, agree with our experimental results rather well. Comparing the experimental and calculated results we should conclude that:
1. the visible knee (not in primary spectrum) in PeV region is connected with iron primaries (this confirms the Tibet ASγ data [6]);
2. the visible proton originated knee lies at primary energy close to 100 TeV (this could be confirmed by another obsevations [4], [7]);
3. to explain these breaks in measured spectrum one need not to introduce the "knee" or "knees" in primary spectrum: it could follow a pure power law with the integral index γ $\approx$-1.7 [2], [3].

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References

[1] Yu.V. Stenkin, A.B. Chernyaev et al. // Izvestia RAN, ser. Fizicheskaya. V. 68. No 11. (2004). P. 1611.
[2] Yu.V.Stenkin. /Does the "knee" in primary cosmic ray spectrum exist?. // Mod. Phys. Lett. A, 8(18), (2003),p. 1225.
[3] Yu.V.Stenkin. //Phys. Atom. Nucl. V. 71, No. 1, (2008), p. 98.
[4] J. Cortina, F. Arqueros and E. Lorenz. // J. Phys. G 23, (1997), p. 1733.
[5] D.D. Dzhappuev, V.V. Alekseenko et al. // Izvezia RAN, ser. Fizich. V.71, No. 4, (2007), p.542.
[6] M. Amenomori, X.J. Bi et al. // Astroph. J., 678, (2008), p. 1165.
[7] A. Haungs and J. Kempa (for the KASCADE). Nucl. Phys. B, 75A, (1999), p. 248.