Why the knee at 100 PeV could not be seen? *

Yu.V. Stenkin a†

aInstitute for Nuclear Research of Russian Academy of Sciences,
Moscow 117312, Russia

It is shown that a ”second (iron) knee” in cosmic ray spectrum expected at energy about 100 PeV could not probably be found there. The reason is very simple: the position of the ”iron knee” depends on an answer to the questions: ”What do we see at 3-5 PeV? Is the knee seen at this energy associated with proton or iron primaries?”

1. Introduction

If the knee at 3-5 PeV in cosmic ray spectrum is a result of a break in primary proton spectrum, as it was claimed by the KASCADE collaboration, and energy of the knee for different primary particles (Z, A) is proportional to charge Z (or atomic number A), then one should expect ”iron knee” existence at ~100 (or 200) PeV. Discovery of this ”iron knee” was one of the main goals for KASCADE-Grande experiment [1]. But, the data obtained in this experiment [2] as well as in all others, up to date did not show any significant change of the spectrum slope in the expected region.

On the other hand, as it is known, the conclusions of Tibet ASγ and Tibet-III experiments [3,4] were the following: ”Our results shows that the main component responsible for the knee structure of the all particle spectrum is heavier than helium nuclei.” It is in strong contradiction with the KASCADE conclusion. If one believes in the Tibet experiment results then one could expect an existence of the ”proton knee” at energy lower by a factor of 26 (or 56 ) than 3-5 PeV, i. e. close to 100 TeV. Unfortunately, their energy threshold was put to 200 TeV and the knee is seen only in comparison with all other data.

2. Phenomenological approach

The reason of the ”puzzle” could be found if one takes into account a new approach to the knee problem [5,6]. In this phenomenological approach primary spectrum could follow pure power law while the knee is expected to be seen in electromagnetic components and its position should occur at energy of ~100 TeV / nucleon for all primary particles. This is a critical point in EAS development when the equilibrium between hadronic and electromagnetic EAS components undergoes a break at observation level. The primary masses A are spread from A=1 for protons through A=56 for iron. Therefore, the knee visible in PeV region should be connected with iron primaries while ”proton knee” is expected to be seen at ~100 TeV. This approach agrees with the Tibet ASγ experiment conclusion that the knee in PeV region is connected with heavy primaries. It should be emphasized that the hybrid method used by the Tibet experiment gave an advantage to this experiment in comparison with a traditional EAS array, resulting in real primary mass selection for individual events (at least for light primaries).

3. Experimental situation

Compilation of the experimental data shown in [2,4] makes us sure that there are no visible knee at energy ~100 PeV. Small change of the slope (steepeing then flattening and then again steepening) shown by the KASCADE collaboration at the European Cosmic Ray Symposium in Turku [7] was obtained by only one method (N_e-N_µ) while other methods gave negative results (see fig. 1). There are no self-agreement of the data and I think it should be proved by other
experiments to be regarded as an "iron knee").

But, a question arises: did anybody see the knee at 100 TeV? The answer is "yes". A technical problem exists for this region - this point coincides, as a rule, for the great bulk of EAS arrays with their energy threshold. But, if the threshold is put well below of 100 TeV then a "knee-like" behavior can be seen. For example, such "knee-like" behavior can be found in results of simulations (fig. 13 in [4]). Unfortunately their experi-

Figure 1. Energy spectra as recovered by KASCADE-Grande experiment using 3 different methods [7]

Figure 2. Integral spectra of the shower size $N_e$ obtained in [8]

4. Conclusion

The problem of the cosmic ray knee in PeV region is still far from its solution. The EAS technique elaborated many years ago allowed physicists to investigate energy regions, which could not be reached with direct cosmic ray measurements. But, as an indirect method, it has many uncertainties and simplifications. Sometimes the result depends on the suppositions made a priori. And the most sensitive it is to a supposition on the existence of the knee in primary cosmic ray spectrum.

On my opinion, traditional EAS arrays can not solve this very complicated problem. One of the best array of the classical type - KASCADE (KASCADE-GRANDE) - did not solve the problem of the knee. It would be very difficult to make better classical array. New approaches and new ideas are needed. The PRISMA project proposed by us [14], would be an alternative array aimed to the knee problem. It based on the idea that hadrons form the EAS structure and thus hadrons should be the main EAS component to be recorded and studied. A grid of a large number of hadron sensitive scintillator detectors spread on the area of $10^4 - 10^5 m^2$ on the ground surface will be used to record two main EAS component: hadronic (through thermal neutrons) and electromagnetic. The project will have many advantages in comparison with the traditional arrays: it will work as a huge area hadronic calorimeter, it will have better core location accuracy, better energy resolution, etc. It could give us a possibility to
measure EAS size spectra not only in electrons but in hadrons and in muons as well. High altitude location is preferable for such experiment. That is why the project could be combined with other high altitude projects, such as LHAASO or HAWC.

Acknowledgements

This work was supported by the RFBR (grants 09-02-12380 and 08-02-01208).

REFERENCES

1. Haungs A., Apel W.D. et al. Investigating the second knee: The KASCADE-GRANDE experiment. ArXiv: astro-ph/0508286, 2005.
2. Blumer V.J., Engel R. et al. Cosmic Rays from the Knee to the Highest Energies. ArXiv: 0904.0725v1, 2009.
3. Amenomori M. et al. Are protons still dominant at the knee of the cosmic-ray energy spectrum? ArXiv: Astro-ph/0511469v1, 2005.
4. Amenomori M. et al.: The All-particle spectrum of primary cosmic rays in the wide energy range from $10^{14}$ to $10^{17}$ eV observed with the Tiber-III air-shower array.: Astrophys. J., v. 678, p. 1165, 2008.
5. Stenkin Yu.V.: "Does the "knee" in primary cosmic ray spectrum exist?": Mod. Phys. Lett. A, 8(18), p. 1225-1234, 2003.
6. Stenkin Yu.V.: Phys. Atomic Nucl. V.71(1), p. 98, 2008.
7. Bertaina M. et al. The cosmic ray energy spectrum in the range $10^{16}$ - $10^{18}$ eV measured by KASCADE-Grande: Report at 22 ECRS, Turku: http://ecrs2010.utu.fi/done/presentations/EDU2/2ApA2Wednesday/5Bertaina.pdf
8. Haungs A., Kempa J. et al. (KASCADE): Report FZKA6105, 1998.
9. Haungs A., Kempa J. et al. (KASCADE): Nucl. Phys. B, (Proc. Suppl.), 75A, p. 248.,1999.
10. Arqueros F., Barrio J. A et al. HEGRA-Collaboration.: Astron. and Astrophys. 359, p. 682-694, 2000.
11. Stenkin Yu.V. et al.: Izvestia RAN, ser. Fizich. V. 68 (11), p. 1611, 2004.
12. Hayashi Y. et al.: Proc. 26th ICRC, v.1, p. 236, 1999.
13. Nesterova M., Chubenko A.P. et al.: Proc. Of 24th ICRC, Rome, v.2, p. 748, 1995.
14. Stenkin Yu. V.: On the PRISMA project.: ArXiv: 0902.0138v1 [Astro-ph.IM], 2009; Yu.V. Stenkin. Nucl. Phys. B (Proc. Suppl.), v. 196, p. 293-296, 2009.