New approach to cosmic ray phenomena generated by VHE particles above the knee

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Abstract

In cosmic ray investigations various unusual events are permanently observed. Among them: excess of VHE muons and muon bundles, different kinds of penetrating and long-flying particles, Centauros and Anti-Centauros, etc. In this talk, taking into account that most of unusual events have energetic threshold that coincides with the knee position, a possibility of their explanation from a single point of view is considered. The key role of VHE muons is stressed.

1. Introduction

Observation of unusual and unexpected events is the normal situation in cosmic ray investigations. It is sufficient to remember the discoveries of muons, strange particles, etc. But on other hand, numerous unusual results obtained in cosmic rays in 60-80 years (prompt and stropping muons, observations of quarks and monopole, and other) were not confirmed in further investigations or in accelerator experiments. This circumstance led to a rather sceptical attitude of most part of physicists to a possibility to obtain reliable results for particle physics in cosmic ray investigations. However, new unusual results, for explanation of which new physical ideas, objects and phenomena are required, continued to appear. Most of them are connected with very high energies, which correspond to PeV interval (and higher) in cosmic ray energy spectrum.

In this paper, the most interesting and impressive unusual results obtained both in muon and in hadron experiments are discussed. The connection between these results and the change of slope of cosmic ray energy spectrum in atmosphere is analysed. A possibility of their explanation from a single point of view in spirit of ideas developed earlier [1, 2] is considered.

2. Muon experiments

At present, muon energy spectrum is known approximately up to 10 TeV with relatively good accuracy and has no serious deviations from conventional predictions of muon flux due to π- and K-decays. Deviations from this spectrum appear at higher energies and their value is increasing with growth of muon

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energy. For example, see Fig.3 in [3], where the results of muon energy spectrum measurements in MSU (cascade showers [4]) and LVD (absorption curve) are shown. Usually, the observed excess of high energy muons is associated with decays of charmed particles. But required for that flux of these particles is very large [4] and is not consistent with theoretical models and available results of accelerator experiments [5]. Besides, incomprehensible is the increase of muon bundles abundance with depth which was observed in LVD experiment [6].

It is especially difficult to explain the detection of VHE muons with energies more than $\sim$ 100 TeV. The first observation of VHE muons was done by Japanese physicists who detected air shower with energy about 300 TeV at zenith angle 86° [7]. For conventional muon energy spectrum, the detection of similar event is very unlikely. Very interesting event in which muon interacted permanently is thick target was observed in NUSEX detector (the picture of this event can be found in [2]). Calculations show that probability of generation of such event by muon with energy appreciably less than 100 TeV is very small.

3. Hadron experiments

A set of unusual events detected in hadron experiments is very wide and is interpreted in terms of specific particle names (penetrating and long-flying particles), special names for different types of events (Centauros, Anti-Centauros), specific features of events (alignment), etc. In Fig.1, a sample of unusual event detected in Pamir experiment [8] is presented. It is important that the particle passed through a thick layer of lead and interacted practically at any depth.

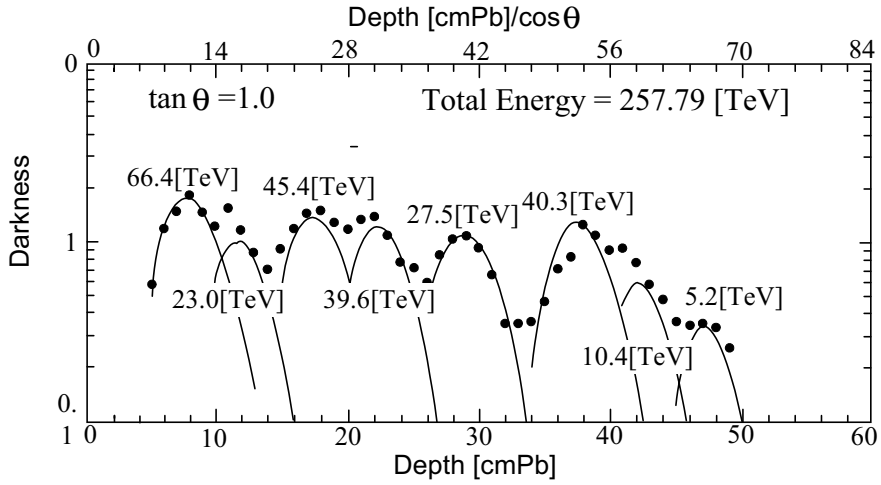

Fig. 1. Penetrating particle detected in Pamir experiment [8].

The terms Centauros and Anti-Centauros are related with violation of isotopic equilibrium between charged and neutral secondary particles. In Centauros, only hadronic component is detected, and in opposite, in Anti-Centauros only electromagnetic cascades are observed. Also, very large fluctuations of N_μ/N_e-ratio measured in extensive air showers may be considered as unusual phenomenon. Though apparently in part these fluctuations are explained by small sizes of muon detectors, nevertheless some part of them evidences for really big fluctuations, which hardly can be explained for large total number of secondary particles.

4. New physics and the knee

Of course, it is impossible to determine the energy of primary particle for each unusual event. In the best case some mean values can be evaluated taking into account average multiplicity of secondary particles generated by primaries in the atmosphere. Such calculations indicate that in many cases the appearance of unusual events is connected with PeV energy interval of primary energy spectrum. It is very difficult to prove, but it is possible to suppose that the appearance of all (or at least of the most part) unusual events is connected with the change of the slope of cosmic ray energy spectrum in the atmosphere.

If to suppose that the slope of primary spectrum is not changed, but some new particles or states of matter at the knee energy are produced, then these new physical objects must be massive ($m \sim$ TeV) and short-lived ($\tau < 10^{-12}$ s). In principle they can be both any particles which are predicted by various theoretical models (supersymmetric particles, preons, etc) and some new states of matter generated in collective interactions of many nucleons (quark-gluon plasma, fireballs, etc). These massive objects can decay into W- and Z-bosons, which in their turn have considerable modes of decays into leptons. In this case, energy of three types of neutrinos and muons will be missing energy for a given interaction, since even muon energy is not measured by muon detectors in existing EAS arrays. The increasing deficit of measured energy results in a change of slope of cosmic ray energy spectrum in the atmosphere.

The idea that the appearance of the knee is connected with the change of particle interaction was discussed from the very beginning after discovery of the knee in 1959, and numerous searches of missing energy in various components of EAS were conducted. But VHE muons were never measured. However, as calculations show, in this case a big excess of muons with energies more than ~ 100 TeV is expected [1, 2].

5. VHE muons – the key for explanation of unusual events in cosmic rays

Naturally, the excess of VHE muons (compared with conventional muon spectrum) can explain all results of muon experiments in which such excess was observed, including muon bundles, since multiple production of VHE muons is possible. But such excess can explain also many unusual results obtained in hadron experiments. VHE muons are very good candidates in penetrating and long-flying particles, since at these energies the character of muon interaction is seriously changed, and VHE muons can interact practically permanently along the track due to electron-positron pair production. Therefore in mountain experiments it is difficult to separate interactions of muons and hadrons, and it is quite probable that the event in Fig.1 was generated by VHE muon.

The production of one or several massive particles will lead to increasing fluctuations in various components of EAS in comparison with production of large number of light particles (pions). This circumstance can explain some unusual events as Centauros and Anti-Centauros, and also N_μ/N_e ratio behavior in EAS.

6. Conclusion

Proposed approach to explanation of various unusual events in cosmic rays, including the solution of the knee problem, gives a possibility to evaluate the main characteristics of new physical object before the beginning of LHC operation. For that, re-analysis of numerous existing experimental data is required. Of course, new experiments on VHE muon spectrum measurements and on the search of coincidences between EAS size and VHE muon appearance are possible, too. Such experiments have been discussed elsewhere [9].

7. References

1. Petrukhin A.A. 1999, in Proc. XIth Rencontres de Blois "Frontiers of Matter", (The Gioi Publ., Vietnam, 2001), 401
2. Petrukhin A.A. 2001, 27th ICRC 5, 1768
3. Aglietta M. et al. 1998, PRD 58, 092005
4. Il'ina N.P. et al. 1995, in Proc. 24th ICRC 1, 524
5. Gelmini G., Gondolo P., Varieschi G. 2000, PRD 61, 036005
6. Ryazhskaya O.G. 2000, NPB (Proc. Suppl.) 87, 423
7. Matano T. et al. 1965, in Proc. 9th ICRC 2, 1045
8. Arisawa T. et al. 1994, NPB 424, 241
9. Petrukhin A.A. 2003, Phys. Atom. Nucl. 66, 517