IL NUOVO CIMENTO Vol. 24 C, N. 4-5 Luglio-Ottobre 2001

# Investigation of unusual phenomena in cosmic rays with *Tien Shan* and *Pamir* experimental setups at energy higher than 1 PeV - I(*)

S. A. Slavatinsky(**)

*P. N. Lebedev Physical Institute, Russian Academy of Sciences*
*Leninskii Prospekt 53, 117924 Moscow, Russia*

(ricevuto il 24 Ottobre 2000; approvato il 12 Febbraio 2001)

**Summary.** — Numerous unusual phenomena observed in cosmic ray experiments at energy > 1 PeV can be effectively studied with modern large-scale combined setups located at high mountain altitudes. Construction in the nearest future of the new setups at *Chacaltaya*, *Tien Shan* and *Pamir* Mountain Stations situated at different altitudes will provide physicists with important additional information on the nature of unusual phenomena. In this report, we discuss the main physics problems that should be investigated by means of the mountain-level setups.

PACS 13.85.Tp – Cosmic-ray interactions.
PACS 96.40.De – Composition, energy spectra, and interactions.
PACS 96.40.Pq – Extensive air showers.
PACS 01.30.Cc – Conference proceedings.

## 1. – Introduction

The problem of the PCR energy spectrum break at energy 3-4 PeV (the so-called *knee*) which was established several decades ago is still one of the most intriguing ones for cosmic ray physicists. Besides, a series of new unusual phenomena and events is observed in various cosmic ray experiments just in the same energy range referred to the knee. The majority of these phenomena is detected in high-altitude experiments by the *Tien Shan* complex setup for EAS research belonging to P. N. Lebedev Physical Institute (3340 m above sea level), by large-scale X-Ray emulsion chambers (XREC) at the Pamirs (4370 m) and Mt. Chacaltaya (5200 m) as well as by the Tien Shan hybrid setup *Hadron* (3340 m) which combined electronic technique for EAS recording with that of XREC.

(*) Paper presented at the Chacaltaya Meeting on Cosmic Ray Physics, La Paz, Bolivia, July 23-27, 2000.
(**) On behalf of the *Pamir* and *Tien Shan* Collaboration.

## 2. – Unusual phenomena

The main samples of unusual phenomena are as follows:

a) So-called *Centauro-type* events were observed in experiments at Mt. Chacataya and the Pamirs by large XREC with carbon target [1]. The specific feature of Centauro-type events are the abnormally high ratio of hadron multiplicity to that of $\gamma$-rays as well as a too high ratio of corresponding total energies which cannot be explained by statistic fluctuations in the framework of conventional models.

b) A phenomenon of coplanar emission of particles in multiparticle production processes was discovered in the *Pamir* experiment [2]. The phenomenon manifests itself as an alignment of tracks of most high energy hadrons and $\gamma$-rays (or their clusters) along a straight line on the target diagram of gamma-hadron families. A sophisticated analysis of experimental data revealed that coplanar events are produced at primary particle energy $E_0^{\rm th} \gtrsim 8$ PeV. A significant feature of the phenomenon in hand is the increase of sensitivity of observable quantities to the coplanar event production in the case of treating the highest energy structures (clusters) inside a $\gamma$-family which are formed by particles of the earlier generations. It means that decreasing of experimental setup elevation should reduce the effect due to its rapid destruction by subsequent interactions in the atmosphere.

Due to the lack of experimental statistics, independent confirmations of the new phenomenon by other research groups are of particular importance. Recently Chinese physicists have re-processed the experimental data from the XREC experiment, formerly carried out by the Japanese-Chinese Collaboration at Mt. Kanbala (5600 m a.s.l.) in China, in order to check a possible strong anisotropy of gamma-hadron families and quantitatively confirmed the effect of coplanar emission of high energy hadrons though employing an essentially lower experimental statistic [3]. Note that Chinese physicists also performed independent detailed calculations of the background due to statistical fluctuations occurring while producing the families. The results of their calculations are completely consistent with those carried out in the *Pamir-Chacaltaya* experiment.

Of particular importance is the observation of the coplanarity effect for large-scale 3-subcore hadron structures inside EAS cores recorded by a large ionization calorimeter at the Tien Shan station [4].

A consistent physical interpretation of the phenomenon is still absent. An attempt to explain the alignment effect in terms of momentum conservation while treating the quark-gluon jet production [5] seems to be not conclusive since it claims the alignment of three-core structures and fails to explain that of four-core structures. Probably the coplanar emission of particles is related to the one-dimensional character of the quark-gluon string rupture [6]. Similar to the case of Centauro and Anti-Centauro event observation, the presence of cascade process in the atmosphere which could erode the coplanarity demands some additional assumptions like the existence of heavy penetrating particles which produce such kind of events. The location of the future experimental setups at different altitudes will make it possible to efficiently investigate this hypothesis and, on the other hand, to avoid plausible negative result in observation of the events at lower altitudes.

c) In XREC experiments at Mt. Chacaltaya and the Pamirs, events were observed with the so-called *halo*, *i.e.* large diffuse dark spot on X-ray film accompanying the high energy particle tracks in gamma-hadron families. Figure 1a) presents an example of halo events in the form of contact image from X-ray film. Calculations reveal that halo is pro-

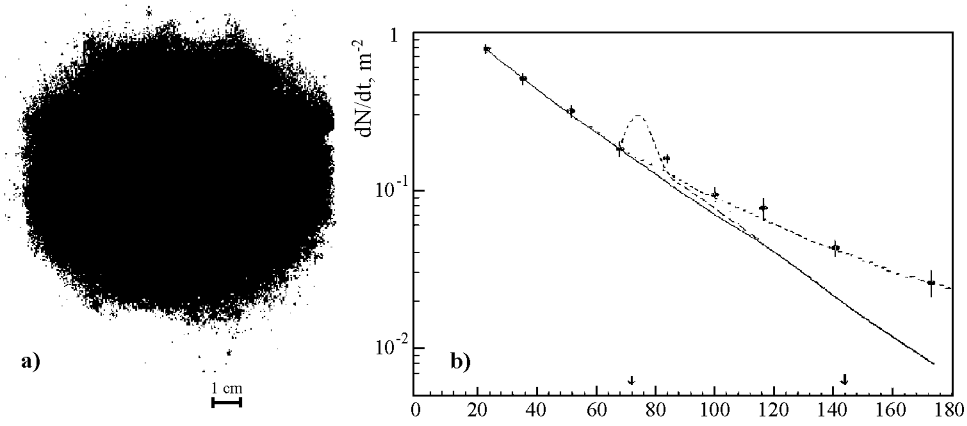


Fig. 1. – Examples of unusual phenomena: a) The *Tadjikistan* halo event. The visible energy within halo is 50 PeV, while the estimated primary energy is 1000 PeV. b) Distribution of cascade origin points in deep uniform lead XREC (• experimental points; solid line stands for expected curve of cascade absorption without accounting for charmed particle production, while dotted line is that with charm production; dashed line is the same curve for XREC with air gap accounting for charmed particle decay).

duced as a rule by an incident narrow bundle of particles providing the observed density of energy flux $\geq 20$ TeV/mm$^2$. Such a bundle occurs obviously not high above XREC (3-6 cascade units). The analysis of the halo area distributions shows an abundance of events with large areas which may be produced by primary nuclei heavier than protons, thus favoring the enrichment in heavy nuclei of the PCR [7].

d) The Pamir experiment collaboration obtained in measurements with deep uniform lead XRECs (120 cm thick) a distribution of origin points of electron-photon cascades induced by penetrating particles which noticeably deviates from an exponential dependence (fig. 1b). This may be explained by a high fraction of charmed particles; however, this assumption requires large cross-section for their production (> 2 mb/nucleon) [8]. The abnormal behavior of absorption curve needs a further study which is going to be carried out by means of a XREC with air gap specially designed for this purpose and already constructed at the Pamirs. Earlier a similar phenomenon was observed in EAS cores at Tien Shan [9].

e) In the recent years experimental researches of time-lateral characteristics of EAS hadron component in the $N_e$ interval from $3 \cdot 10^5$ to $10^8$ have been carried out at the Tien Shan by the hadron-combined setup supplemented with the neutron supermonitor 18NM-64 which is used as a detector of EAS hadrons with energy greater than 50 MeV [10].

The detection process in the 18NM-64 supermonitor goes in the following way. EAS hadrons interacting with the monitor lead absorber split lead nuclei. As a result of this, evaporated neutrons occur which are slowed down in the monitor up to thermal energies and then detected by neutron counters. The specially designed detection system of the monitor makes it possible to observe the neutron flux within 3.5 milliseconds from the moment of the EAS front passage. An unusual time behavior of the neutron flux detected by the monitor was noticed from the very beginning of the investigations. In

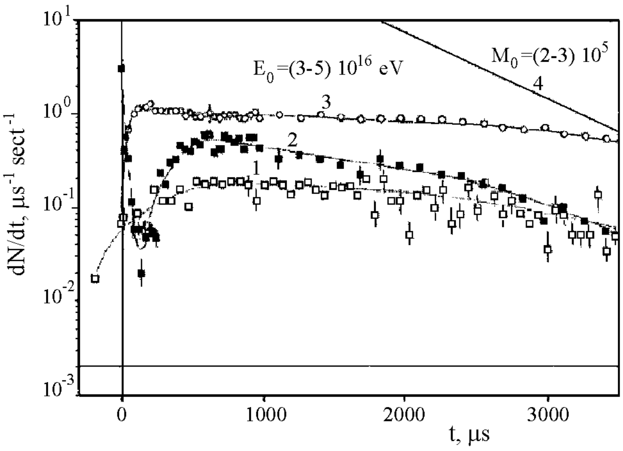


Fig. 2. – Time distribution of detector countings for a given EAS; 1) charged component, 2,3) neutron one, 4) $f(t)$ curve with corresponding estimation of $M_0$.

all EAS events for which the neutron number $M$ in a monitor module does not exceed 1000, the neutron flux changed with time in accordance with the processes of neutron thermalization and diffusion in the monitor [11]. However, the neutron flux decreased with time in a much slower way in EAS events with $M > 1000$ (fig. 2).

The phenomenon is so new and unusual that it is hard to get insight into it. Perhaps, it is related to the abnormally delaying (for hundreds and more microseconds) EAS component whose energy is hard to detect by shower arrays without specially arranged detection system. The probable result of this is an underestimation of primary particle energy.

It is worth noting that the assumption of conventional time behavior of neutron flux in the monitor results in extremely large fluxes of hadrons in EAS (2-3 times higher than the expected ones).

## 3. – Peculiarities of the PCR energy spectrum

a) The Tien Shan EAS array with a calorimeter and a center carpet (distances between scintillation detectors were less than 1.5 m) detected an abnormally high fraction (> 15%) of EAS with narrow and steeply decreasing lateral distribution functions which correspond to shower age $S < 0.5$ among those with electron number $N_{\rm e} > 5 \cdot 10^6$ ($E_0$ higher than several units of PeV). Note that the fraction of EAS with $S < 0.5$ is only a few percent at $N_{\rm e} < 10^6$.

According to the hadron experiment data the fraction of EAS with $S < 0.5$ increases with $N_{\rm e}$ and begins to dominate at $N_{\rm e} > 10^6$. Note that such type of showers could be detected only by an array with high detector density in the center of it, *i.e.* with small distances between detectors (from 5 to 20 m at the Tien Shan) while ordinarily these distances amount to hundreds of meters in large arrays. Another peculiarity of EAS in this energy range is that the main part of them arrives on the Earth from the plane of the galactic disk where the main Galaxy sources are located. This reveals an important role of primary particles with energies higher than 1 EeV which slightly deviates by the galactic magnetic field and make it possible to realize an idea of nucleon astronomy of

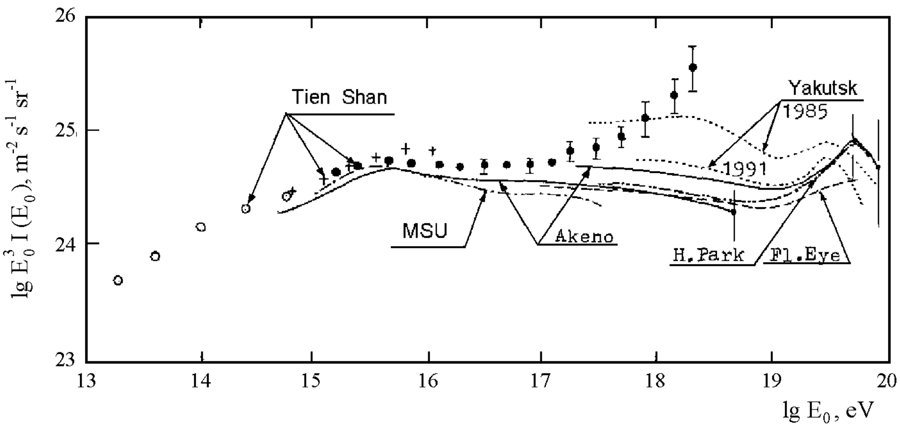


Fig. 3. – Energy spectrum of primary cosmic rays.

superhigh energies.

Perhaps the possibility to detect narrow EAS is the reason of discrepancy between the spectrum measured at Tien Shan and those determined by other large arrays (*Akeno, Yakutsk, Fly's Eye, Havera Park*) at energies $E_0 > 100$ PeV (fig. 3) [12].

It is important to note that the Tien Shan spectrum of PCR has the second (reverse) break at energy $E_0 \simeq 100$ PeV beyond which it restores within experimental errors the shape it has before-the-*knee* energy range ($E_0 < 3$–$5$ PeV). The problem of existence of the second PCR spectrum break is a new one and needs a particular attention by astrophysicists.

b) Figure 4 presents the comparison of data by the hadron setup on gamma-ray families accompanied by EAS with simulated results. Calculations were performed with the MQ1n code [13] employing the quark-gluon string (QGS) Model supplemented with the high-$p_t$ jet production mechanism which is widely used now in both accelerator and

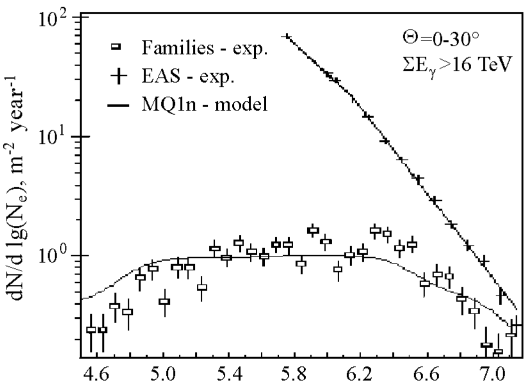


Fig. 4. – Differential spectra of $N_e$ for all EAS and for those with $\gamma$-families. The solid line is a calculation with the quark-gluon string model MQ1n.

cosmic ray studies. Calculations fit showers with families noticeably worse than all EAS with respect to both spectrum shape and slope index dependence on $N_e$. Spectrum irregularities are just in the same region of all other anomalies, *i.e.* $N_e > 10^6$. The analysis shows that the spectrum irregularities ("fine structure" of spectrum of EAS accompanied by families) may indicate an appearance of excess protons or some unusual particles like strangelets [14] within narrow energy ranges.

## REFERENCES

[1] Slavatinsky S. A., *Nucl. Phys. B (Proc. Suppl.)*, **52** (1997) 56.
[2] Borisov A. S. *et al.*, *Izv. Akad. Nauk SSSR (Ser. Fiz.)*, **49** (1985) 1285.
[3] Xue L. *et al.*, in *Proceedings of the 26th ICRC (Salt Lake City)*, vol. **1** (1999) p. 127.
[4] Pavluchenko V. P., *Bull. Leb. Phys. Inst.*, **6** (1998) 3.
[5] Halzen F., Morris D. *et al.*, *Phys. Rev. D*, **42** (1990) 1435.
[6] Royzen I. I., *Mod. Phys. Lett. A*, **9** (1994) 3517.
[7] Borisov A. S. *et al.*, *Nucl. Phys. B (Proc. Suppl.)*, **52** (1997) 185.
[8] PAMIR Collaboration, *Bull. Soc. Scien. Lettr. (Lodz)*, **13** (1992) 133.
[9] Dremin I. M. and Yakovlev V. I., in *Proc. 17th Conference on Multiparticle Dynamics, Seewinkel 1986*, **1** (1986) 849.
[10] Aushev V. M., Zhdanov G. B. *et al.*, *Izv. Akad. Nauk SSSR (Ser. Fiz.)*, **61** (1997) 488.
[11] Chubenko A. P. *et al.*, in *Proceedings of the 21st ICRC (Adelaide)*, vol. **9** (1989) p. 73.
[12] Nesterova N. M. *et al.*, in *Proceedings of the 25th ICRC (Durban)*, vol. **4** (1997) p. 173.
[13] Dunaevskii A. M. *et al.*, in *Proc. 7th ISVHECRI, Ann Arbor 1992*, **1** (1992) 540.
[14] Vildanova I. I., Shaulov S. B. *et al.*, *Izv. Akad. Nauk SSSR (Ser. Fiz.)*, **58** (1994) 79.