The Modern Status of Anomalous Delayed Particles Effect in the "Knee" Region EAS according to the Data of Tien Shan Mountain Station

A.P.Chubenko,[1] A.L.Shepetov,[1] V.P.Antonova,[3] S.V.Kryukov,[3] R.A.Mukhamedshin,[2] M.N.Nesterova,[1] V.V.Oskomov,[6] V.V.Piscal,[4] T.Kh.Sadykov,[5] and L.I.Vildanova[4]
(1) P.N.Lebedev Physical Institute, Russia
(2) Institute of Nuclear Research, Moscow, Russia
(3) Ionosphere Institute Almaty, Kazakhstan Republic
(4) Tien-Shan mountain scientific station of LPI, Almaty, Kazakhstan Republic
(5) Institute of Physics and Technik, Almaty, Kazakhstan Republic
(6) Al-Faraby Kazakh National University, Almaty, Kazakhstan Republic

Abstract

Attempts to explain the extra high multiplicity neutron events having peculiar prolonged time distributions of particle intensity ("neutron bursts") without any exotic assumption concerning the EAS nature lead to contradictions with the usual models of EAS cascade development. The supposition that these events could be a consequence of experimental distortion demands again the presence of enormous hadron flows 50-100 times greater than the EAS theory predicts.

1. Introduction.

In experiments with NM64 type neutron supermonitor being carried out since the beginning of 1990-th at the Tien-Shan mountain cosmic ray station are constantly observed the unusual events with extremely high neutron multiplicities (about 1000–3000 of registered neutrons per monitor unit). The similar "neutron bursts" are described also in the work [4]. Characteristic feature of these peculiar events is the strong deviation of their neutron intensity time dependencies from the exponentially decreasing function

$$\frac{dm}{dt} = MF(t); F(t) = [\frac{0.72}{\tau_1}exp(-\frac{t}{\tau_1}) + \frac{0.28}{\tau_2}exp(-\frac{t}{\tau_2})] \qquad (1)$$

with relaxation time values $\tau_1 = 250 - 300\mu$s and $\tau_2 = 600 - 650\mu$s which is typical for the NM64 type monitor as a rule. As it is seen in Fig.1, in our experiment this decrease has been absent until some milliseconds, i.e. during 3-5 relaxation periods after the EAS passage. A similar shape have in these events time distributions of the electrons and photons accompanying the neutrons (see

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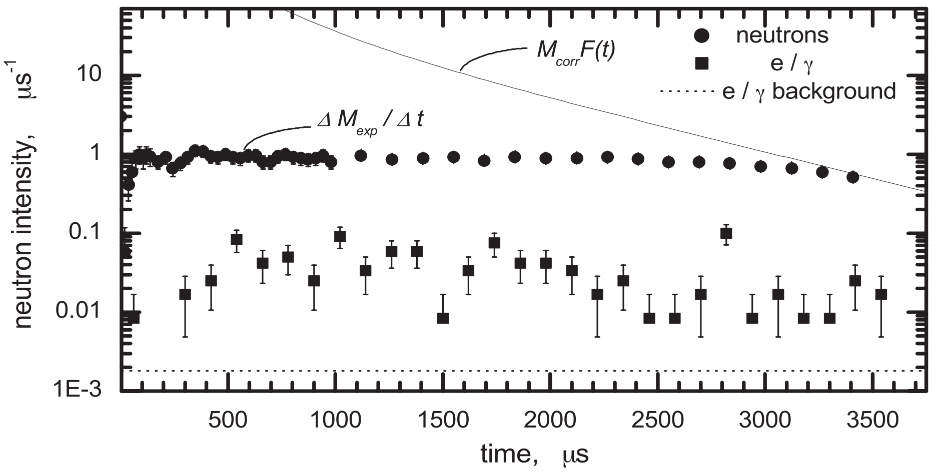

Fig. 1. Example of a "delayed" high multiplicity neutron event ($M_{exp} = 2800$).

Fig.1). Detailed review of the properties of delayed neutron events have just been published in [1]. It is stressed in this article that the delayed events are observed in the cases, when the cores of the EAS with $N_e > 10^6$ (belonging to the above-the-knee range of primary cosmic ray spectrum) fall immediately on the top of a neutron monitor. According to the opinion being insisted on in [4], the delayed time distributions may be imitated in the process of neutron intensity measurement due to the overloading of registration channels in the conditions of a shower core passage. Discussion of such a possibility is the subject of present article. The analysis is based on the statistics registered during 23600 hours of a three-unit NM64 monitor operation in 1996-2002 years.

2. Correction of the neutron multiplicities

One of the main characteristics of the neutron events being studied in our experiment is the total number of neutrons registered inside a neutron monitor's unit — the neutron multiplicity M. It is this parameter which appears as a proportionality coefficient in formula (1). In our work [2] is shown the dependence of the M on the average energy of incoming hadron in the range below 1 TeV where M remains below 300. In the present paper we consider the high multiplicity region $M > 500$ where the passages of EAS cores through the monitor are prevailing.

If we suppose that the original reason of the deviation of experimental neutron intensity curve from the standard law (1) is fully connected with the methodical features of the process of neutron registration, then we have to decide, that the real coarse of neutron intensity continues to follow to function (1) until the highest values of neutron multiplicity — so, as it is shown by a continuous curve in Fig.1. In such a case the value of multiplicity M_{exp} calculated according

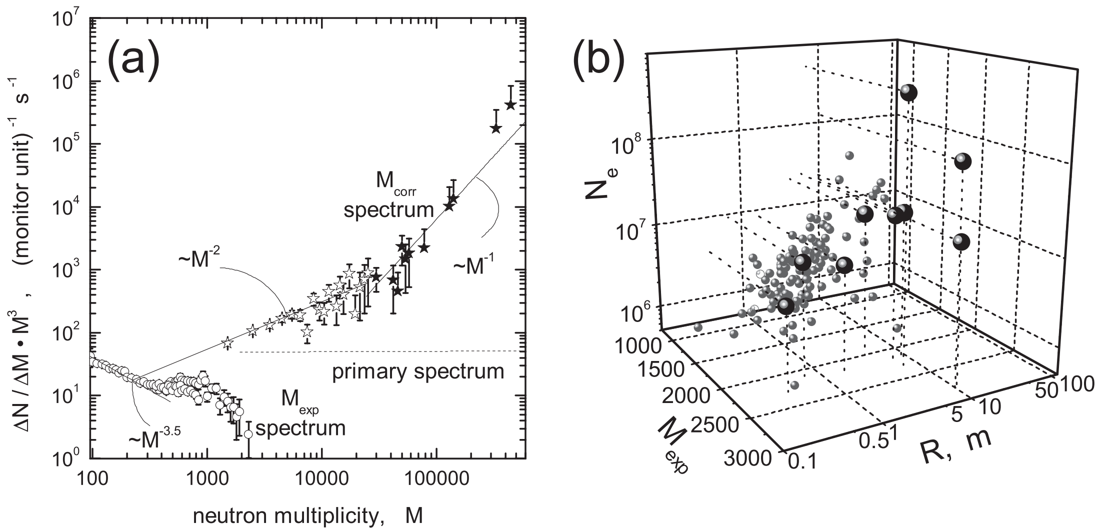

Fig. 2. (a) Neutron multiplicity spectra with (M_{corr}) and without (M_{exp}) correction of multiplicity values; (b) the "$M - N_e - R$" correlation plot for high multiplicity neutron events.

to experimental measurement would be strongly underestimated comparatively with the true value M_{corr}, which could be obtained as an integral of the function (1) normalized by such a way to coincide with experimental intensity points in the range $t = 2.5 - 3$ ms.

3. Discussion

Fig.2a represents the differential M_{exp} and M_{corr} neutron multiplicity spectra in comparison with each other. It is seen that the first, "experimental", spectrum corresponds to a usual power dependence with a slope index between 3.0–3.5 and breaks near multiplicity values about 3000. In the contrary, the "corrected" M_{corr} spectrum seems to have an extremely hard shape, lasting until the multiplicity values of the order of $10^4 - 5 \cdot 10^5$. The slope of this spectrum has the value about 2.0 until $M_{corr} \sim 5 \cdot 10^4$ with the tendency to have a value about 1.0 in the range $M_{corr} > 5 \cdot 10^4$ (!).

As is well known, the energy spectrum of primary particles in this energy range has the slope index about $3.0 - 3.3$. According to traditional opinion, the hadron number in EAS is connected with it's primary energy as $N_h \sim E_0^\alpha$ where $\alpha = 0.75 - 0.8$ (may be, $\alpha \sim 1$ in the core region), consequently the spectrum of the hadron numbers N_h must have the slope index $\gamma = 3.5$. Because the average hadron energy E_h in EAS does not practically depend on the primary energy E_0, the neutron multiplicity must be proportional to N_h and it's spectrum cannot have the slope index below 3.0. *The last sentence contradicts directly to our above result concerning the slope index of M_{corr} spectrum.*

If the average hadron energy E_h in the EAS cores were increasing with E_0, the M_{corr} spectrum must be softer than the primary one. Indeed, according to the data of Tien Shan ionization calorimeter, the spectrum of energy deposits of EAS cores hadron component in the above-the-knee region has the slope index 2.87 [3]. The registered energy of a shower core hadrons is $E_{core} = N_h \cdot E_h$. The neutron number M is connected with the energy of an incoming hadron as $M \sim E_h^{0.5}$ [2] and is proportional to N_h (i.e. M depends on E_h weekly and is determined mostly by the N_h value). The mean hadron energy E_h should be decreasing with the E_0 increase. If E_h were increasing, the neutron multiplicity can diminish only. *To produce a number of neutrons which would be compatible with our M_{corr} estimation a great amount of low-energy hadrons is necessary.*

Thus, the supposition of methodical deviation of registered neutron numbers leads to conclusion about the presence of a huge flow of low-energy hadrons in the core region of EAS and the decrease of average hadron energy with E_0 increasing. *This result distinctly conflicts with the modern EAS development models of a quasi-scaling type.*

The above discrepancy is especially noticeable in the neutron events of extremely high multiplicity ($M \sim 2000$). Fig.2b shows a correlation plot between the values of shower size N_e, shower core distance from the monitor unit's center R and the neutron multiplicities M for a sample of high multiplicity events. It is seen, that the events with $M \sim 2000$ are registered mostly at the distances 5–10 m apart from the core of the showers with $N_e \sim 10^7 - 10^8$. We particularly considered the $N_e > 10^7$ events (bold points in Fig.2b) calculating in each case the ratio between the densities of e/γ-component ρ_e and registered neutron densities ρ_n after our correction procedure had been applied. The resulting ρ_n value occurred to be 2–3 times higher than ρ_e, which demands the corresponding hadron density ρ_h having a value above $0.1\rho_e$. *The last estimation contradicts to usual EAS models: the total hadron number N_h in showers with $N_e > 10^7$ can not exceed $0.01N_e$.*

Therefore, the refusal from the non-methodical nature of the delayed time distributions of neutron intensity seems to be a premature one.

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4. References

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