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Registration of new stable heavy charged particles in cosmic rays

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ABSTRACT. A telescope of two coaxial scintillation detectors (an upper $\varnothing$63x0.35 mm^2 thin CsI crystal and a lower thick $\varnothing$150x100 mm^2 NaI crystal) positioned vertically on the Earth surface has recorded 23 events within T=106 hours. All the events (except for three background events) are within two standard deviations from a curve calculated for singl?-charged non-relativistic particles with mass M_E = (175±25) GeV/c^2 that traverse the telescope from a vertical. On assumption that the particles recorded are not relativistic, from the geometrical size of the telescope it follows that their lifetime is $\tau_E > 1.5\cdot10^{-9}$ s. Their intensity in cosmic rays on the Earth surface $J_E = (1.8\pm0.4)10^{-6}$ cm^{-2}sr^{-1}s^{-1} (at $E_E \leq 6$ GeV, $P_E \leq 50$ GeV/c). This particles recorded conform completely to our phenomenological predictions, to our earlier experimental results obtained when searching for particles like those, and to the predictions of the «mirror» model that offers theoretical support to the existence of the hypothetical stable heavy hadrons (*Erzions*).

INTRODUCTION. The hypothesis about new penetrating stable heavy hadrons [1,2] was proposed to explain the anomalous slope of cosmic muon energy spectra [3,4,5]. Many of the characteristics of the hypothesized hadrons (mass, charge, lifetime, intensity, nuclear interaction mode, interaction and absorption paths) were predicted phenomenologically to harmonize the very copious anomalous and ordinary experimental cosmic ray data and to make them consistent. There are many different experiments in cosmic rays, which indicate on existence of stable heavy particles [6-15], but there are no any simple and correct proofs until now. Later, we made attempts to find them experimentally [16-21] and to construct a model that would offer a theoretical support to their long lifetime ($\tau > 10^{-5}$ s), given their very high mass (M>30 GeV/c^2). The pioneer attempts were made using the super symmetrical model [22], but the use of the «mirror» model $U(1)xSU_l(2)xSU_r(2)xSU(3)$ [23-24] proved to be more successful. The present-day standard models [25] fail to explain that long time of the heavy elementary particles in terms of weak interaction. The theoretical ideas about the structure of hypothetical heavy hadrons, given a better understanding of their interaction mode, have permitted the heavy hadron search experiments to be designed more consistently on the basis of the purpose-oriented underground facility of the Institute of Nuclear Physics of the Moscow State University (40 m.w.e., $S\Omega \sim 10^3$ cm^{2}sr). The facility consists of a continuous-medium vertical magnetic spectrometer (P_{max}=700 GeV/c) and six rows of large-area ($S=2\cdot10^4$ cm^2) plastic scintillators positioned beneath the spectrometer to detect particle stoppages. The facility has operated for ~200 hours and detected three appropriate events of the sought particles ($J_E \cong 4\cdot10^{-8}$ cm^{-2}sr^{-1}c^{-1}), which we interpreted at that time to be background events [18-19].

INSTALLATION. For different reasons, unfortunately, the experiments with the second- and third-generation equipment [20-21], which was cheaper and simpler in use, have failed to yield any positive results. In this work we have realized the simplest fourth-generation equipment to search for stopped heavy charged particles in cosmic rays. The experimental facility is a vertical telescope composed of a pair of coincidence-mode scintillation detectors (SD) (see Fig.1). The upper detector, SD1, is a thin CsI crystal ($\varnothing$63x0.35 mm^2) coupled to a PM-110 photomultiplier; the lower detector, SD2, is a thick NaI single crystal ($\varnothing$150x100 mm^2) coupled to a PM-49 photomultiplier. High voltage is supplied from a BNV3-0,5 source to PM-110 and from the SBS-50M analyser chip (see below) to PM-49 (see Fig.1).

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The two crystals are spaced 50 mm coaxially apart, so the telescope aperture is $S\Omega \cong 30\ cm^2 sr$. The hopes for success when using a low-transmission telescope are based on the hypothesis for the sought particles [1,2], which predicts the particle intensity at sea level to be $J(P_E \geq 100\ GeV/c) \cong 10^{-6}\ cm^{-2} sr^{-1} s^{-1}$. If the mass of the hypothetical *Erzions* [23,24] is $M_E \geq 100\ GeV/c^2$, they cannot be relativistic at such a high intensity, which is very important in the proposed method for detecting them [17]. On the other hand, the experimental equipment of all the earlier generations was placed at small depths (~40 m.w.e.) to reduce the cosmic ray background. At the same time, *Erzions* should be absorbed markedly at so small depths due to ionisation loss in the non-relativistic range (by a factor of about 100 at $M_E=200\ GeV/c^2$) despite the fact that *Erzions* are actually the penetrating hadrons with absorption path L=100 m.w.e. due to their nuclear interactions with matter. So, the remarkable novelty of this experiment is the fact that the experimental equipment is placed on the Earth surface, thus making it possible to increase the effect substantially despite a likely increase in the background.

The upper thin SD1 is intended for measuring specific ionisation (dE/dx) of charged particles as inside of SD1 so at the SD2 inlet, while the thick SD2 measures the total energy release: $E=(dE/dx)_{mean} \cdot h$. The SD2 crystal is thick enough ($\rho \cdot h=36\ g/cm^2 \sim$ 4 radiation units) for electromagnetic cascades to develop effectively therein, the fact that probably makes the background conditions deteriorate. Nevertheless, such a thick layer has been chosen deliberately to provide for effective stoppages of the sought particles in the crystal, so that the specific ionisation would vary strongly along the rest of the particle paths. The pulses from either SD-s are recorded (see Fig. 1) with a C8-17 dual-trace memory oscilloscope with the coincidence time 0,5 μs. Besides, the telescope was adjusted and monitored to check on its proper performances by recording the pulses also from either SD-s with a «Greenstar» Co-made SBS-50M multichannel (8192 channels) analyser chip built into an IBM-PC, as well as with an AI-1024 multichannel analyser.

The expected distributions of the SD1 and SD2 pulse amplitudes (A_1 and A_2) were calculated using the Bethe-Bloch and Bragg curves and the path-energy functions plotted for singly charged particles of different masses (10, 150, 200, 1000 GeV/c^2) on the basis of the similar curves for protons in different media [26,27,28]. The A_1 and A_2 values are presented in their normalized form in units of the amplitudes that are most probable to occur in the differential spectra of amplitudes induced by separate relativistic cosmic ray muons in either of the SD-s (μ_1, μ_2).

RESULTS. During 106 hours of its operations, from July 6 to 30, 1999, given the event selection thresholds $A_1 \geq 11\mu_1$ (counts intensity ~ 0,1 s^{-1}) and $A_2 \geq 10\mu_2$ (counts intensity ~ $3 \cdot 10^{-3}\ s^{-1}$), the telescope detected 23 events in which the amplitudes A_1 and A_2 were observed simultaneously. Fig.2 shows the events together with the theoretical curve for non-relativistic protons and hypothetical singly charged heavy particles with masses of 10, 150, 200, and 1000 GeV/c^2. The calculations were made assuming that the non-relativistic hadrons loose their energy for ionisation only, so their nuclear interactions can be disregarded, i.e., they behave lepton-like. Also, the fact is essential that, at given such a high specific ionisation, the CsI and NaI scintillation crystals fail to show the quench effect, which occurs in organic crystals and in plastic scintillators [27].

In accordance with the Pearson fitting criterion [27], almost all of the experimental points (except for three) are within the confidence domain of two curves calculated for singly charged heavy particles with masses of 150 GeV/c^2 and 200 GeV/c^2, namely $\chi^2=0.95$. The fact is of great importance that the falling branches of the two curves adjoin the points corresponding to the particle stoppages inside SD2 and permitting the mass of a sought particle to be estimated reliably.

From the condition of the particles being non-relativistic (V<0.3 c) and allowing for the telescope dimensions (l=d+h=15 cm) it follows that their lifetime τ must be longer than their flight time in the telescope (t=l/v); hence $\tau_E > 1.5 \cdot 10^{-9}$ s.

During the 106 hours-long experiment, 20 sought particles were detected. The recorded particle mass is $M_E=175 \pm 25\ GeV/c^2$, the particle ionisation $A>10\mu$ ($E_E \leq 6$ GeV, $P_E \leq 50$ GeV/c) proved to be increased, and the particle intensity is

$$J_E = N/S\Omega T \cong 20/(106 \cdot 3600 \cdot 30) = (1.8 \pm 0.4) \cdot 10^{-6}\ [cm^{-2} sr^{-1} s^{-1}],$$

which is in a good agreement with the expected intensity [1,2] and does not contradict three «appropriate» events recorded at 40 m.w.e. underground (see the above explanations). Meanwhile, all three «appropriate» events were of negative charges as recorded by the magnetic spectrometer, just what follows from the Erzion model of the hypothetical particles [23,24].

DISCUSSION. At first sight, the events recorded can be explained in the simplest way by showers charged-particle sizes N>10 with a 10 MeV energy of each particle and lateral size r~1 cm at the SD1 detection level. However, this explanation contradicts the events in the falling branches of the curves in Fig.2. Besides, if the cascades are nuclear and have been initiated by protons in the matter of the lower part of PM-110 ($\delta \sim 1\ g/cm^2$), they must be of intensity $J_k \leq 10^{-9}\ cm^{-2} sr^{-1} s^{-1}$ [28-31], which is much below the intensity of the detected events (the nuclear showers initiated in the upper part of the photomultiplier will have lateral size r >>1 cm). The proton interaction probability (the proton interaction path is $\lambda_p \cong 100\ g/cm^2$) must be $W_p=\delta_p/\lambda_p \sim 0.01$.

Nuclear showers with charged-particle sizes N>10 can only be initiated by the $E_p>100$ GeV protons, whose intensity in cosmic rays at sea level is $J_p<10^{-7}\ \mathrm{cm^{-2}sr^{-1}s^{-1}}$. From the fact that $J_k=J_p\cdot W$ it follows that the above statement $J_k\leq 10^{-9}\ \mathrm{cm^{-2}sr^{-1}s^{-1}}$ is true.

Any trivial process can never interpret two events that are most significant in the falling branch of the calculated curve. If, for example, they are assumed to be produced by relativistic Be nuclei ($A_2\sim16$) that deposited an additional energy of 7 MeV in SD1 (say, due to scattering) and, thus, generated a pulse amplitude $A_1\sim36$ in SD1 (just as in the case of two interpreted events), then their intensity will be $J=J_{Be}\cdot W_{Be}=10^{-8}\cdot10^{-2}\ \mathrm{cm^{-2}sr^{-1}s^{-1}}=10^{-10}\ \mathrm{cm^{-2}sr^{-1}s^{-1}}$, which is three orders as low as the intensity of the interpreted events.

Three background points above the curve may be interpreted to be generated by showers or relativistic ^{4}Be ($A_1\cong A_2\cong16$) and ^{7}N ($A_1\cong A_2\cong49$) nuclei. One of the three points occurs just within this domain ($A_1=53$, $A_2=42$). Two other points lie above the calculated ionisation loss curve for multiply charged particles, the fact that can be explained by an additional energy release in the SD2 crystal due to a nuclear interaction therein. The probability for the nuclear events to occur on the calculated ionisation loss curve is about the same as the probability for them to occur above the curve because the nuclear interaction path is comparable with the SD2 crystal thickness ($\lambda\cong\rho\cdot h$). The intensity of the three events ($J\sim10^{-7}\ \mathrm{cm^{-2}sr^{-1}s^{-1}}$) corresponds exactly to the intensity of relativistic nuclei in cosmic rays at sea level.

CONCLUSION. The author considers that, since not a single trivial explanation can account for the events recorded, he has discovered a new species of stable heavy charged particles in cosmic rays (*Erzions*) whose parameters are:

mass $M_E=(175\pm25)\ \mathrm{GeV}/c^2$, lifetime $\tau_E>1.5\cdot10^{-9}$ s,

intensity in cosmic rays on the Earth surface $J_E=(1.8\pm0.4)\cdot10^{-6}\ \mathrm{cm^{-2}sr^{-1}s^{-1}}$ at $E_E\leq6$ GeV and $P_E\leq50$ GeV/c.

The events recorded [32,33] are quite in agreement with our phenomenological predictions, with the earlier experimental results of searching for the hypothetical particles, and with the predictions of the «mirror» model that offers a theoretical support to the feasibility for the hypothetical stable heavy hadron (*Erzions*) to exist actually.

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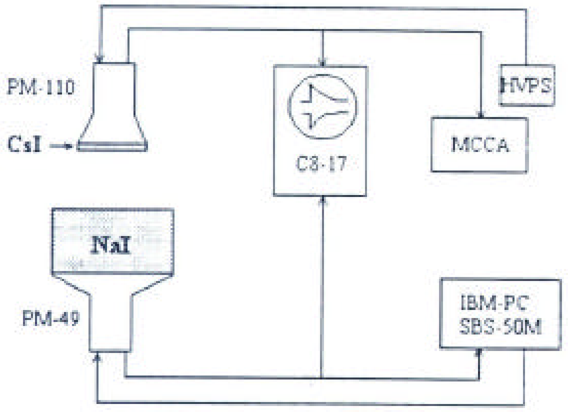

Fig 1 Installation block-scheme

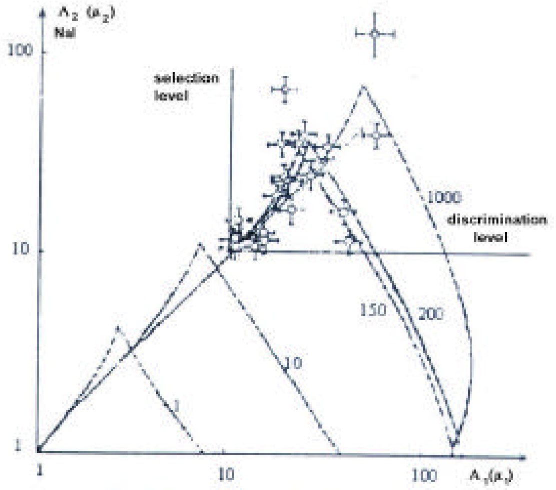

Fig 2 Detector amplitude correlation