# RESULTS OF A SEARCH FOR MONOPOLES AND TACHYONS IN HORIZONTAL COSMIC RAY FLUX

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Abstract. A search for monopoles and tachyons at ground level has been carried out using an arrangement consisting of an ionization calorimeter and two hodoscope detectors. No clear evidence for these particles has been obtained. The flux of monopoles with velocities $\beta \gtrsim 10^{-2}$ is found to be less than $5.1 \times 10^{-13}$ $cm^{-2}s^{-1}sr^{-1}$(95% c. l.). The upper limit on the tachyon flux density is set as $6 \times 10^{-9}$ particle/cm$^2$event.

1. Introduction. In spite of the fact that monopoles and tachyons are absolutely different objects the search for these particles has been conducted using the same experimental arrangement. A detailed description of the detector used in the experiment, the motivation and first results have been published elsewhere [1-3]. The arrangement consisted of a six-layer ionization calorimeter and two G.-M. counter hodoscope detectors, and

i) events in the calorimeter with approximately equal ionization of more than 100 cascade particles observed in all six layers have been selected as monopole candidates;

ii) muon induced cascade showers in the calorimeter were used as reference events to search for preceding particles (tachyons) produced in high energy collisions in the upper atmosphere.

Present paper sums up results obtained during five experimental runs in 1980 - 1984. The total observation time exceeded $2.2 \times 10^4$ hours so available statistics have been doubled in comparison with the publications at the previous conference [2,3].

2. Monopole. If the massive monopole would traverse the calorimeter the ionization in all six layers would be approximately equal. In our experiment trigger signals were generated when ionization in any three layers of the calorimeter exceeded a threshold level 80 cascade particles (c.p.) within the time gate of 40 $\mu$s. The events with the measured ionization $\gtrsim 40$ c.p. in all layers of the calorimeter and with the angle between the particle trajectory and calorimeter axis less than 55° have been selected for the analysis.

The ratio of the maximum measured ionization to the average one was used as a quantitative criterion of equal ionization:

(1) $$R = I_{max}/(\sum_{j=1}^{6} I_j/6)$$ , where j is the layer number.

In a real experiment even in the case of equal ionization R may appreciably deviate from the unit due to measurement errors. We estimate the upper limit of r.m.s. ionization measurement error as 20%. Assuming that errors followed to the log normal distribution we calculated the distribution of events as a function of R for the case of uniform ionization along calorimeter depth (dashed curve in Fig.1).

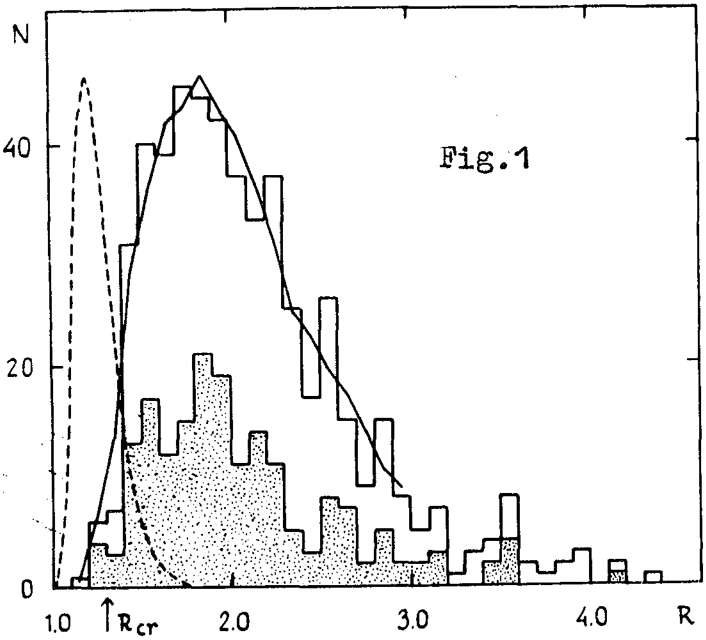


Fig.1

The observed distribution for six-layer events with average ionization of more than 100 c.p. (solid histogram in the figure) drastically differs from that for uniform ionization. We suppose that all these events are cascade showers. To estimate the background from the showers the Monte Carlo simulation of six-layer events was performed (broken line). A good agreement of this calculation with experimental data gives the evidence that all six-layer events represent a background.

The ionization from a single heavily ionizing particle must be localized in one or two adjacent chambers in every layer. This fact permits to cut the shower events due to their wide transversal ionization distribution. The events selected in accordance with this additional restriction are presented by the shaded histogram in the figure. Finally, hodoscope information was used to reject shower events which are often accompanied by plural fired counters in the exit detector.

In the previous paper [2] we used $R_{cr} = 1.5$ to separate possible monopole events from shower ones. However, calculations showed that the optimal value of $R_{cr}$ is equal to 1.3 which corresponded to monopole selection efficiency $\geq 65\%$.

With the above criteria no monopole candidates were found. Taking into account the geometric acceptance (11.3 $m^2 sr$), available operation time ($8 \times 10^7$ s) and selection efficiency (0.65) we have estimated the upper limit of monopole flux from the top hemisphere as $5.1 \times 10^{-15} cm^{-2} s^{-1} sr^{-1}$ (95% c.l.). According to theoretical calculation for monopole energy loss [4] the ionization range $\gtrsim 100$ c.p. corresponds to monopole velocities $\beta \gtrsim 10^{-2}$.

3. Tachyon. The situation around the tachyon hunt is rather complicated. There are almost no theoretical predictions concerning the interactions of these superluminal particles, therefore it seems reasonable to use every possible means to found tachyons. Our experiment is based on the assumption that tachyons are very common particles: i) tachyons may be produced in high energy collisions of primary nucleons in the atmosphere or in the decays of any secondaries; ii) they can arrive to and be detected on the Earth surface; and iii) the efficiency of their registration by G.-M. counters is not equal to zero.

Tachyons may be identified as particles which arrive the observation point earlier than other particles produced in the same interaction. High energy cascade showers initiated by muons in the ionization calorimeter were used as triggers while potential tachyons were detected by hodoscope only. The number of triggering muons was $\sim 8\times10^4$ for the minimal cascade shower energy ~20 GeV. The effective energies of muons and those of primary nucleons corresponding to this threshold were ~100 GeV and ~1 TeV, respectively.

The time and arrival direction information from hodoscope detectors was recorded in the time interval $T \simeq 26$ ms before the trigger, but the delaying events were also analysed for the comparison. Only preceding and delaying particles with trajectories parallel to those of triggering muons have been selected. The observed events are presented by points in the ($\Delta T$ - cos $\theta$) diagram (Fig.2). There is no apparent difference between the preceding ($\Delta T < 0$) and delaying ($\Delta T > 0$) particles.

The fly-off time between the relativistic muon and preceding or delaying particle depends on the particle velocity $v$ and the distance from the primary nucleon interaction altitude to the observation point L, which in its turn depends on the zenith angle $\theta$ and the interaction depth in the atmosphere x: $\Delta T = (1/v - 1/c)L(\theta,x)$. (2)

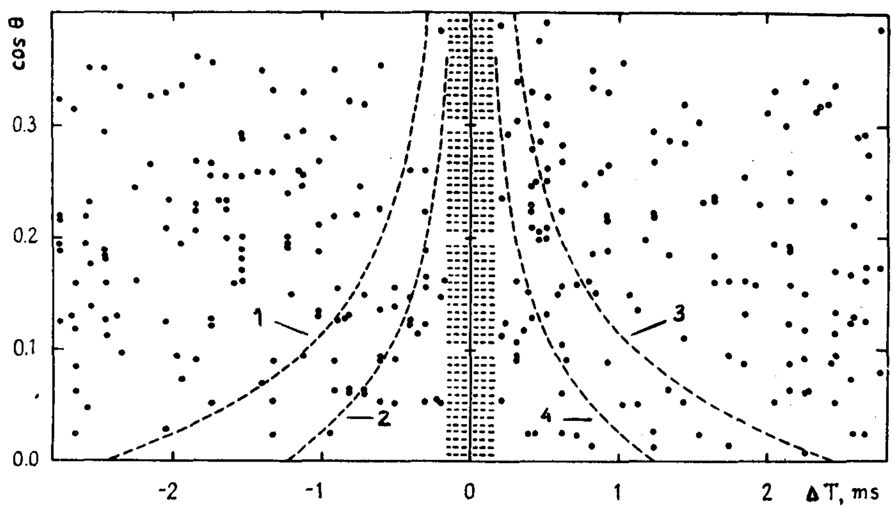


Fig.2

Since in our experiment the large zenith angles ($\theta \geqslant 60°$) are accessible, values of L were calculated for x = 12.6 g/cm$^2$ depth along the particle trajectory. Assuming a 120 g/cm$^2$ nucleon absorption length, this value corresponds to 10% attenuation of primaries so 90% of tachyons would be produced at such or shorter distances. The curves 1 and 2 in the figure give the angular dependence of $\Delta T$ for preceding particles with velocities $v = \infty$ and $v = 2c$ correspondingly. Since there are no predictions about the definite tachyon velocity we considered the case of arbitrary velocities, i.e. all events under the curve 1. The observed number of these events was 39. The curves 3 and 4 are drawn symmetrically for the comparison. The number of delaying particles under the curve 3 was 47. The expected value of the background was calculated considering: i) area under the curve 1, ii) angular distribution of muons, and iii) the total number of events in 26 ms interval, and was equal to 37.0 ± 1.7. The sumed collecting area of the hodoscope detectors constituted $3.0 \times 10^9$ cm$^2$. Taking into account the hodoscope efficiency (of about 0.8) the upper limit of the density of tachyons associated with high energy muons was estimated as $6 \times 10^{-9}$ particle/cm$^2$ event.

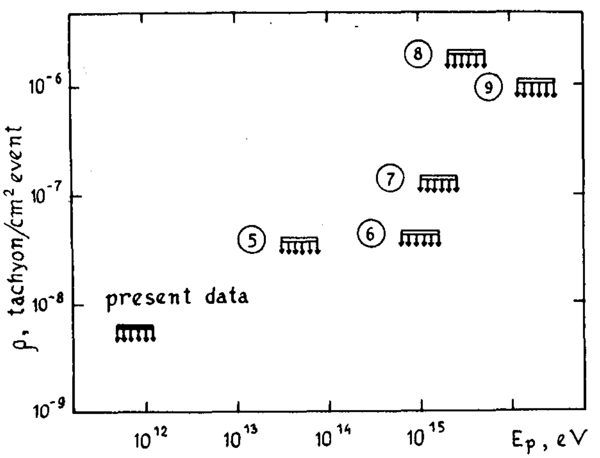


Fig.3

The direct comparison of our results with other searches for tachyons is complicated since only few authors give quantitative limits. Therefore we estimated upper limits of tachyon densities using the published experimental data[5-9] as follows:

$$(3) \qquad \rho \leqslant 3\sqrt{n \cdot \Delta T \cdot N} \,/\, S \cdot N,$$

where n is a background rate; S is the area of the tachyon detector; N is the number of triggers; $\Delta T$ = 100 $\mu$s is the preceding time interval for the vertical direction ($v = \infty$, x = 12.6 g/cm$^2$). Results of these calculations are presented in Fig.3. Ciphers near the bars correspond to the reference numbers.

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