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# Tachyons in extensive air showers?

(Research of "delayed" EAS's with $N_e > 5 \cdot 10^6$ particles)

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**Abstract:** "Delayed" EAS's with $N_e > 5 \cdot 10^6$ particles were registered. Registration of such events shows presence of new processes at energies above $10^{16}$ eV.

## Introduction

Research of delayed particles in extensive air showers began over 40 years ago [1], and many papers (see bibliography in [2]) are devoted to it.

Recent paper [3] is devoted to research of delayed neutrons, electrons and photons in EAS. It is shown, that delayed particles are concentrated in a circle with radius ~(15÷30) meters from EAS axis. The calculations performed in [4] on model QGSJET-II+Gheisha 2002d, have shown, that the majority of observed delayed neutrons were produced directly in the neutron monitor, instead of coming together with EAS. Higher multiplicity of produced neutrons and their concentration near to EAS axis are caused by narrow lateral distribution EAS hadrons around the axis. Delayed electrons and photons also have a secondary origin. They are produced by delayed neutrons in an environment of the monitor.

The majority of other works investigating delayed particles in EAS, are devoted either to research of thickness of a shower disk at various distances from the axis, or to attempts to register heavy particles.

In the study [5] performed at the sea level, 4 scintillators, placed in corners of a square with a diagonal 6,5 m were used for measurement of delayed particles. Besides 70 detectors placed in a square with the side of 50 m, were used for definition of EAS parameters. In 18 events from 6162 detected one of detectors registered a delayed impulse, with density of particles $10 \div 20$ $m^{-2}$. From them in 4 events delayed impulses were detected in 2 detectors. Authors came to the conclusion, that these events are caused by a heavy (several tens GeV) particle with the life time about $5 \cdot 10^{-7} \div 2 \cdot 10^{-6}$ seconds.

In work [6], performed at the sea level, two groups of scintillators with area of each 4 $m^2$ were disposed at distance 22,5 m from each other. Signals in every group were summarized. Events were taken into consideration, when a delayed impulse exceeded the signal from one relativistic particle and differed from a basic signal more than on $3\sigma$, where $\sigma$ is the standard deviation in distribution of basic impulse arrival time at fixed distance from EAS axis. In 760 events from 26000 detected there were a delayed impulses in one of groups, and in 9 events delayed impulses were observed simultaneously in two groups. The density of shower particles in a delayed shower (in one of the examples presented in paper) was 1,25$m^{-2}$, and the total number of particles in a delayed shower (after integration over a circle with a diameter 150 m) turned out to be $N_e \geq 88357$ particles. Authors believe that the appearance of delayed at equal time impulses in 2 scintillator groups indicate on possible existence of delayed "disc" of particles generated by heavy long lived particle.

Later this group had analyzed [7] pulse shape in EAS with a particle density more than 10 $m^{-2}$ at core distance $R \geq 200$ m. Result received indicates the non-statistical temporal structure of the pulses.

In work [8] it was used the possibility of GREX-COVER-PLASTEX experiment to analyze arrival time distribution of particles on the shower front. Authors pointed out that they had detected delayed "sub-showers". They couldn't get any self-consistent explanation of the observed phenomenon. "Results instead are consistent with the observation of long lived massive particles".

Experimental approach used in [5,6] rather remind those we used.

## Description of array

In this experiment the installation was located at 3340 m a.s.l. (681 g/cm$^2$) and consisted of 16 detectors, 10 of which was arranged along the circle with radius ~65 m, one disposed in the array center and 5 along the circle with R~130 m. Detector consists of phototube FEU-49, on which photocathode the scintillator with diameter of 15 cm and thickness of 5 cm was placed. Triggering system selects 6-fold coincidences between the central detector and those 5 disposed along the inner circle. The signals from 4 detectors along 200 m cables come to inputs of 4 channel oscilloscope TEKTRONIX TDS 2014. Collected information is recorded by PC.

## Results and analysis

For the period ~5000 hours it were detected 2117 showers with number of particles above $10^7$, in 98 from these events impulse delay for the time from 40 up to 600 ns was registered with number of particles n≥5 passed through the detector, namely with density of particle flux ≥283m$^{-2}$.

In 14 events delayed impulses were registered in 2 and more detectors, in 6 events - in 3 and more detectors, and in 3 events - in all 4 detectors. In the latter case the total number of particles being integrated over the circle with radius 62,5 m exceeds $5\cdot 10^6$! Some parameters of 14 pointed events are presented in the table 1. Event № 53-32 with delayed impulses in 2 detectors is shown in fig.1. Delayed impulses are ~80 ns behind the main impulse. Event №58-130 with delayed impulses in all 4 detectors is shown in fig.2. Here delay equals ~(80-100) ns. Different position of pulses at abscissa is conditioned by different time of EAS arrival to each detector.

Average delay between main and delayed showers is 109±6 ns and the exponent of decreasing delay distribution is 79 ns. We believe, that events with delayed impulse registered in only single detector are conditioned by the geometry of shower coming and that such events have approximately the same number of particles in the delayed shower.

Table 1

| Run-event | Detector number | Delay Δτ, ns | Zenith angle θ | Azimuth angle φ |
|---|---|---|---|---|
| 53-32 | 2 | 80 | 26 | 206 |
| 53-69 | 2 | 130 | 20 | 218 |
| 54-130 | 2 | 60 | 54 | 47 |
| 55-35 | 3(4?) | 115 | 5 | 149 |
| 55-85 | 3 | 80 | 31 | 171 |
| 58-130 | 4 | 80 | 35 | 200 |
| 58-148 | 3 | 75 | 42 | 126 |
| 59-24 | 4 | 70 | 24 | 102 |
| 76-5 | 4 | 95 | 29 | 265 |
| 83-10 | 2(3) | 125 | 32 | 280 |
| 91-36 | 2 | 125 | 29 | 58 |
| 170-161 | 2 | 190 | 7 | 298 |
| 172-257 | 2 | 180 | 34 | 289 |
| 172-309 | 2 | 150 | 33 | 37 |

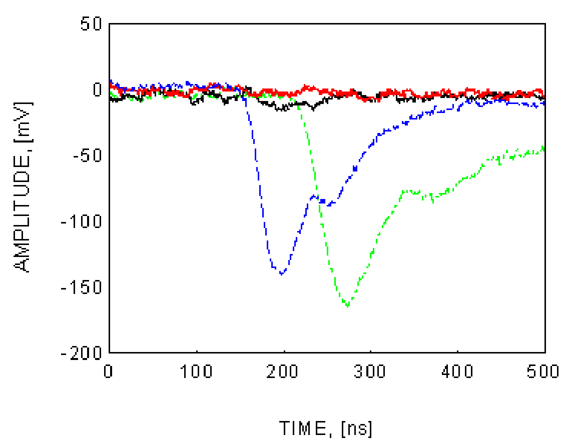


Fig.1. Event 53-32

Let us assume that the delayed shower starts deep in the atmosphere after second interaction of leading particle. To detect one particle by our detector the local density of particles in EAS should be ~57 m$^{-2}$. The density of particles in EAS with $N_e$ = $2.75\cdot 10^7$ at distance 200 m from shower axis is ~25 m$^{-2}$. Thus effective radius for registration of such showers by our array is less than R=200 m.

The delay $\Delta t$ for the shower started deep in the atmosphere (at distance $Z_2$ above observation level) in comparison with those started at $Z_1$=50 km above Tien-Shan level (see fig.3) is:

$$\Delta t(Z_2) = (\sqrt{(Z_2^2 + R^2)} + Z_1 - Z_2 - \sqrt{(Z_1^2 + R^2)})/c$$

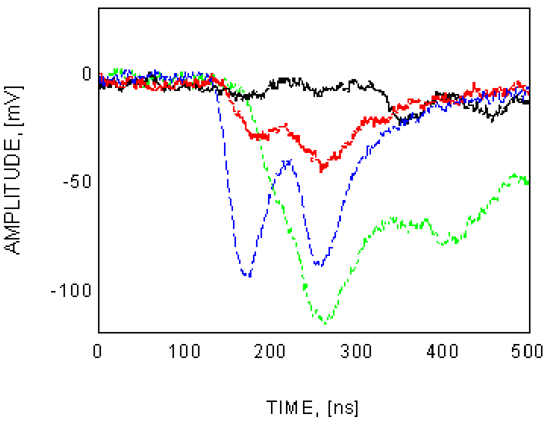


Fig.2. Event 58-130

To be detected the second shower should start at $Z_2 \geq 2.5$ km (~6 cascade unites). Then the delay time is $\Delta t$=25 ns for a detector at R=200 m from the shower axis and $\Delta t$~40 ns for a detector at R=250 m from the shower axis. Only for $Z_2<2.5$ km value of $\Delta t$ slowly increases, but EAS can't make mature at such distance to array.

Thus delay of the second shower is less than those found in our experiment and such explanation of our results fails. It is important also that the delay value is different for detectors placed at different distances from the shower axis.

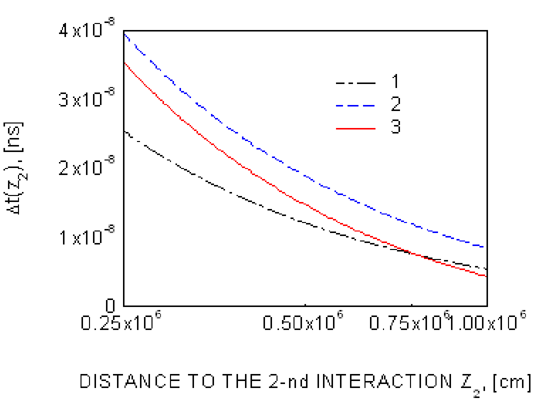


Fig.3. 1- R=200 m, $Z_1$=50 km; 2- R=250 m, $Z_1$=50 km; 3- R=250 m, $Z_1$=16,7 km

It were performed the calculations of arrival time of EAS particles at different distance intervals $\Delta R$ from shower axis. It was used in calculations the model close to QGSJET. All processes were taken into account in calculation of electromagnetic cascade. For electrons they were -bremstrahlung, multiple coulomb scattering and ionization losses. Geomagnetic field influence was also taken into account. For photons they were: pair production and Compton scattering. For EAS with $E=10^{17}$ eV results are shown in fig.4. It is seen from the figure that for our array only detectors disposed at $R\leq80$ m are sensitive for registration of EAS with $\langle N_e \rangle \cong 5{,}7\cdot10^7$ particles. No secondary peaks were found in calculations for our detectors.

Let us assume that the delayed shower is an accidental small local shower. The probability to detect such shower in one detector as found from our data is 98:2117=0,04629.

Then the expected number of such showers detected simultaneously by 2 detectors is $(0{,}04629)^2\times2117$=4,537 compared to 14 detected (4,4$\sigma$). The expected number of simultaneous registration of accidental small local showers by 3 detectors is 0,21 compared to 6 detected, and the expected number of simultaneous registration of accidental small local showers by 4 detectors is 0,009722 compared to 3 detected (30$\sigma$).

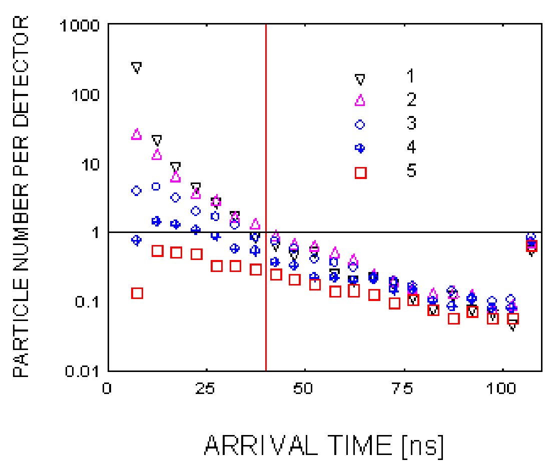


Fig.4. Particle arrival time distributions: 1- $\Delta R$=0-20 m; 2- $\Delta R$=20-40 m; 3- $\Delta R$=40-60 m; 4- R=60-80 m; 5- $\Delta R$=80-100 m

At Tien-Shan the intensity of EAS with $N_e>10^6$ particles is $3,5\cdot10^{-7}$ $m^{-2}s^{-1}sr^{-1}$. The number of such showers which cross our array (circle with R=65 m) every second is 0,00465. The probability for such showers to cross our array per time interval equal to 1μs (the gate of the trigger) is $4,65\cdot10^{-9}$. Thus the probability of accidental registration of such delayed showers is completely excluded.

## Discussions

Likely it is difficult to account for the appearance of giant delayed showers by the neutrons diffused from the EAS core, because the complex of the main and delayed impulses has similar form in different detectors placed from each other at a distance more than 100 m. Calculations [4] performed in the assumption of near standard interaction model of primary proton show that the total number of neutrons out of EAS core is rather small.

To ensure the shower time delay $\Delta t\sim10^{-7}$ s received in the experiment at crossing EAS the atmosphere, the value of $\gamma= E/mc^2$ should be in the interval 10÷30. The energy of delayed shower $E\cong(1\div2)\cdot N_e$ GeV. It follows from here that the mass of generated particle (or pair of particles) which produce delayed shower must be extremely huge: $m\cong E/\gamma = 5\cdot10^{15}/30$ eV $= 1,5\cdot10^5$ GeV!!! Such assumption most likely should be abandoned.

At present time we can launch two assumptions on the nature of delayed showers. According to the first one they can be generate by the abundance of low energy hadrons produced say at the quark-gluon plasma excitation and consequent cascading in the atmosphere.

According to the second assumption "delayed" shower is produced by usual hadrons moving at light velocity, but "outstripping" (advanced) shower is produced by tachyon which was born in the first interaction and moves with velocity exceeding the velocity of light. Tachyon accelerates when losing the energy and the shower which it produces outstrips the shower produced by the conventional hadrons. It is possible to assume that "outstripping" shower produced by tachyon must be μ-less shower.

Both the assumptions are not trivial and we would be grateful for offer of another, more realistic explanation.

Any case the delayed EAS's with $N_e>5\cdot10^6$ particles demonstrate the presence of new processes at energies above $10^{16}$ eV and we continue their investigations.

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