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Search for Heavy Particles with M $>$ 100 GeV in the cosmic ray flux

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Abstract. The results of the analysis of the experimental data on searching for heavy particles in the cosmic rays flux at mountain altitudes at energies $1 - 30TeV$ are presented. An event interpreted as a neutral particle with the $M \gtrsim 700GeV$ and lifetime $\sim 10^{-5}s$ was observed. The estimated intensity of such events amounts $\sim 10^{-12}cm^{-2}s^{-1}ster^{-1}$.

1 Introduction

The problem of searching for new particles is still urgent in high energy physics. When they are detected, the entire classes in elementary particles theory are affirmed (or closed). They may on additional fundamental forces that exist in the nature along with the strong, electromagnetic, week and gravitational ones.
The search for new particles is mainly carried out in experiments on accelerators. However the ultrahigh-energy cosmic rays may be an efficient source of heavy particle production. At $E > 100TeV$ the interactions between the primary cosmic rays and air nuclei may result in production of heavy particles with a mass of handreds GeV (Mamidjanyan et al. , 1987). These particles can be detected by the ground based installations by characteristics of the dicay products, provided they are long-living (Azaryan et al. , 1976).
The heavy particles in a cosmic rays flux can be detected in two ways: by measuring the delay time of the heavy particle after EAS arival (the heavy particle is delayed due to the small Lorentz-factor), as well as by detecting decay products of the hipotetical particle (the theory predicts obligatory decay of a heavy particle exept ones with a conserved quantum number) (Klages et al. , 1998).
By following to the second approach we used the experimental material accumulated during the exploitation of "Pion" installation in 1980-1986 (Avakyan et al. , 1983), in order to search for heavy particles.

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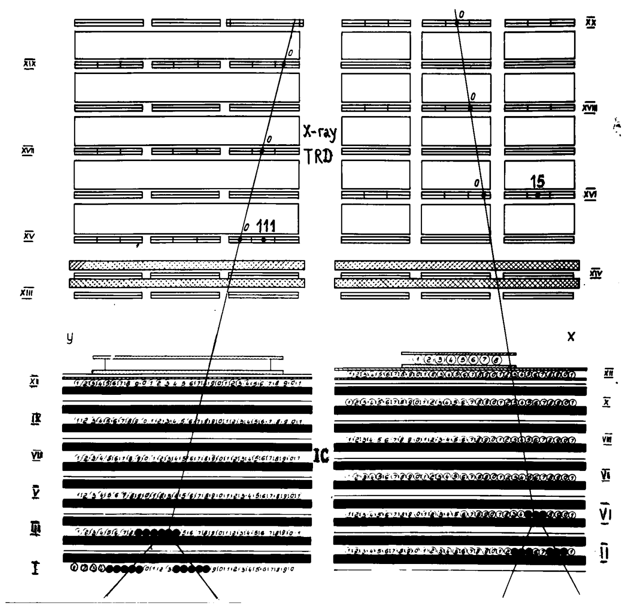

Fig. 1. The schematic view of the "Pion" setup and the view of the event detected.

2 The experimental setup

The "Pion" installation was consisted of an ionization calorimeter (IC), X-ray transition radiation detector (X-ray TRD), and shower detector for EAS detection.
The IC of $\sim 10m^2$ area and $\sim 2.3m$ height together with the X-ray TRD has a geometric factor ~ 2. Ionization chambers for detection of nuclear electromagnetic cascades (NEC), hA-interaction products and for determination of direction of hadron entrance to the installation were located in mutually perpendicular directions in alternating rows between 12 absorbtion layers. Two upper layers of the absorber were made of lead

being of $3cm$ and $2cm$ thickness, respectively. The other 10 layers were made of iron, 10cm thick each. The ionization chambers of 330cm lengt, 10cm diameter have brass 0.3cm thick walls and were filled with argon under 5atm pressure. Total thickness of IC matter was $\sim 1000 g/cm^2$. Particle energy was determined up to 15%, arrival angle - up to $\sim 2^o$ errors. The master condition energy threshold was $\gtrsim 500$GeV. The X-ray TRD was consisted of 5 modules. Each module consisted of laminated medium and multiwire proportional chambers (MWPC). In one plane 27 MWPC were located. The charge and type of the primary hadron, number of accompanying particles and albedo particles were determined by the X-ray TRD. In alternating rows of the X-ray TRD the informational MWPC wires were located in mutually perpendicular directions to determine the direction of the particle entrance to the installation. The MWPC sensitivity threshold was ~ 2 KeV.

The shower detector consisted of 50 scintillator counters on $200 m^2$ area was used to register extensive air showers of the energy $> 10^{12}$ eV. Sensitivity threshold of organic scintillation counters of 5cm thickness was ~ 5 MeV.

The triggering condition of the installation was the presence of energy release $E \gtrsim 500$ GeV in IC, and the presence of NEC at least in four rows of the calorimeter.

The number of accompanying particles was determined by MWPC indicators of the X-ray TRD and scintillation carpet.

Search for heavy particles was realized as follows: The events were considered (by trajectories) when more than one hadron (i.e. NEC) were clearly observed in the IC, and the energy of each hadron was defined separately. Trajectories of hadrons were passed througth the centre of gravity of NEC in IC and through MWPC of the X-ray TRD with a possibility of intersection of hadron trajectories in the calorimeter or above the installation.

3 Data analysis

Among $\sim 10^5$ events processed (10% of these were single-core) one event was observed in which trajectories of two hadrons have been intersected in the IC. In the other events trajectories of all the hadrons were nearly parallel, or the cascades were merged in the calorimeter , so further processing of these events were impossible.

In this event of curiosity the trajectories have been intercrossed in the 4-th row of the IC (the lowest row of the IC was considered to be the first), at a depth $> 600 g/cm^2$ (see Figure 1). Both cascades were developed from almost the same vertex and had nearly the same energy. Information on the presence of the passage of accompanyig particles was absent in the scintillation carpet. Out of 180 MWPC in the X-ray TRD only two MWPC has been operated.

In Figure 1 the numbers 15 and 111 in the X-ray TRD correspond to the values of ionization losses of these particles given by indications of the amplitude converter unit (ACU) (the indication unit of the ACU in MWPC corresponded to

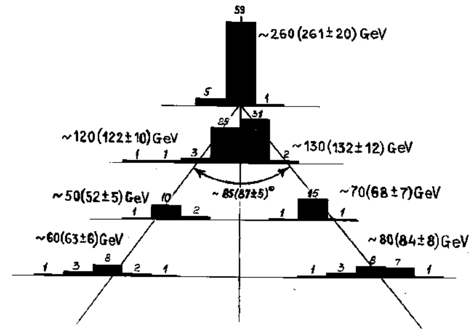

Fig. 2. Results of processed event.

~ 0.14 KeV). The MWPC work can be qualified either as random or as a detection of slow neutrons of the energy $> 10 MeV$ (neutron detection was considered as a local operation of MWPC, i.e. it was impossible to pass a trajectory of the charged particle through the MWPC of the X-ray TRD (Avakyan et al. , 1989)).

It was possible to estimate the probability of random detection of such an event in IC and X-ray TRD. By our estimates it is $< 10^{-15}$.

Figure 2 presents results of analysis of this event. Cascade development in IC rows is shown. The numbers near the cascade refer to fluxes of particles passing through the ionization chambers (each number corresponds to the indication of one chamber) in terms of the ACU. Ibidem is given a total value of energy deposited in a row in GeVs for each cascade individually (the indication unit of the ACU in IC refers to ~ 4GeV). The figure presents results without account of correction for the angle of cascade development. The angle correction results in the fact that the values of energy in the left and right cascades became the same.

The angle between two cascades that develop from one point of IC is $\sim 87^o$.

Total energy deposition in IC is ~ 770 GeV without account of energy carried away under the lower base of IC. If this energy is taken into account (by the method used to precise the energy of solitary hadrons (Kobayashi, 1986)), then total energy is $\gtrsim 1180$ GeV. Particle trajectory passed through the X-ray TRD shows that the particle is neutral (no information on charge passage through six rows of MWPC) (see Figure 1).

Thus, by taking into account the spatial development of each cascade, the energy of each cascade is $\gtrsim 590$ GeV. At the known energies of cascades and the angle between cascades, as well as by neglecting the mass of decaying particles compared with their energies, we can estimate from kinematics the rest mass of a decaying particle which amounts: $M_0 \gtrsim$ 770 GeV.

Let assume this particle is a secondary, i.e. it was generated in atmospheric matter as a result of interaction of the primary cosmic rays with air nuclei.

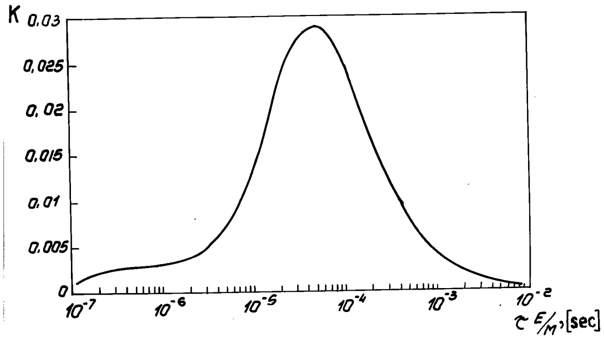

Fig. 3. The dependence of the probability of particle detection by decay products in the installation upon particle lifetime.

We can estimate decay probability of the given particle in our installation. It is:

$$W = \sigma^{\nu} \cdot V \cdot I \cdot \rho \cdot K, \quad (1)$$

where σ^{ν} is the production cross section of the given particle in interactions of primary radiation with the air nuclei (we will assume that $\sigma^{\nu} \simeq 10^{-2}\sigma^{tot}$), $V = 25m^3$ is the volume of our installation, $I = 10^{-9}m^{-2}sec^{-1}ster^{-1}$ is the intensity of the primary cosmic rays flux at energies $E \gtrsim 10^{17}$ eV, $\rho = 2.5 \cdot 10^{19}cm^{-3}$ is the density of the air atoms at installation level, K is a quantity dependent on particle lifetime and Lorentz-factor. It is:

$$K = \frac{1}{\tau_0 c} \cdot \int_0^{\infty} exp[-\frac{h}{\tau_0 c} - \frac{h}{h_0} - \sigma^{tot}\rho h_0 exp(-\frac{h}{h_0})]dh, \quad (2)$$

where h is the height of event observation ($h = 3.25$ km), h_0 is the barometric height ($h_0 = 8$ km), σ^{tot} is the total cross section of inelastic interaction of primary radiation with air nuclei ($\sigma^{tot} = 300$ mb), τ_0 is the particle lifetime (for simplicity we neglect Lorentz elongation of lifetime.

Proceeding from (1) and (2), the probability of particle detection by decay products in the installation is strongly dependent on particle lifetime).

Figure 3 presents the dependence of K on particle lifetime. As one can see from Fifure 3, it is maximal at $\tau = 5 \cdot 10^{-5}$ sec.

By substituting all the available data into formula (1) and assuming the particle lifetime to be 10^{-5} sec, we obtain $W = 10^{-1}years^{-1}$. So long as our experiment lasted about 7 years, it may be considered that the results and the predictions are in agreement.

4 Conclusion

Thus, experimental results allow to conclude that neutral particle with mass ~ 1 TeV and lifetime $\sim 10^{-5}$ sec is detected. The estimate of (1) is close to the obtained value of mass for a heavy particle. By following our experimental data we can estimate intensity of these particles. It is: $I \lesssim 10^{-12}cm^{-2}s^{-1}ster^{-1}$.

As it is known from the theory, the particle lifetime is inverselly proportional to its mass ($\tau^{-1}(GeV) \sim \alpha \cdot M$). So, in order a particle with a mass $\sim 1TeV$ would have a lifetime 10^{-5} sec ($\Gamma \sim 10^{-15}$ GeV), its interaction constant at transfer momentum 1TeV must be $\sqrt{\alpha} \sim \sqrt{\frac{\Gamma}{M}} = \sqrt{\frac{10^{-15}}{10^{-3}}} \sim 10^{-10}$.

What conditions must be observed on installations in order to detect heavy particles efficiently?

- The installation must have a possibility to start at two and more operations in remote local places of the installation, and the ionization calorimeter should have an absorber $\sim 1500g/cm^2$ and a good resolution.
- The installation after detection of fast EAS must be open for detection of the slow accompaniment at least for ~ 150 ms.

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