acta phys. slov. 27. (1977), No. 4

STUDYING HIGH ENERGY COSMIC RAYS BY USING EMULSION STACK CONNECTED WITH IONISATION CALORIMETER

ИЗУЧЕНИЕ КОСМИЧЕСКИХ ЛУЧЕЙ ВЫСОКОЙ ЭНЕРГИИ ПРИ ПОМОЩИ ЭМУЛЬЗИОННОГО БЛОКА, СОЕДИНЁННОГО С ИОНИЗАЦИОННЫМ КАЛОРИМЕТРОМ

J. DUBINSKÝ, L. JUST, Košice*
A. J. SOMOGYI, Budapest**
S. SUGAR, B. CHADRA, Ulan Batar***
B. BAICAN, M. HAIDUC, S. NEAGU, T. VISKY, Bucharest****
Y. BASINA, S. BRIKKER, N. GRIGOROV, M. KONDRATYEVA, L. MISHCHENKO,
R. NYMMIK, L. PAPINA, A. PODGURSKAYA, L. POPEREKOVA, I. RAPOPORT,
V. SOKOLOV, V. SOBINYAKOV, Ch. TRETYAKOVA, L. CHIKOVA,
V. SHESTOPEROV, Zh. SHOPENBERG, Moscow*****

In the paper there are presented results of interactions of nuclei with nuclei at energies $E \geqq 10^{12}$ eV. It is shown that there exists a class of interactions which does not correspond to the superposition of independently interacting nucleons of the impacting nucleus with nucleons of the target nucleus.

On the board of the satellite "Intercosmos-6" there the BFB-S apparatus was placed for studying high energy cosmic rays.

In this apparatus a big emulsion stack was located between two track spark chambers having a good depth discrimination ability. The spark chambers together with the stack were located over the ionization calorimeter of a rather small thickness. Over the upper spark chamber the scintillator detector CC-1 for determining the space angle was placed, in which the particles were registered; it enabled also the crude estimation of the primary particle charge (Fig. 1). The second scintillator CC-2 was located between the stack and ionisation calorimeter and served for the registration of primary particle interaction events in the stack.

The spark chambers were photographed by pairs of photoapparatuses. The following processing of these photographs enabled to obtain the spatial picture of particles passing through the chambers. The whole information about the work of the apparatus was also registered on an X-ray film.

The spark chambers were triggered when in the ionisation calorimeter an energy of not fewer 5×10^{11} eV was registered, then the detector CC-1 was switched on and through the detector CC-2 at least 4 particles were passing.

---

* Institute of Experimental Physics, Slov. Acad. Sci., Moyzesova 11, CS-041 54 KOŠICE.
** Central Research Institute for Physics, H-1525 BUDAPEST.
*** Institute for Physics and Technology, ULAN BATAR, Mongolia.
**** Institute of Atomic Physics, BUCHAREST, Roumania.
***** Institute of Nuclear Physics, Moscow state University, MOSCOW, USSR.

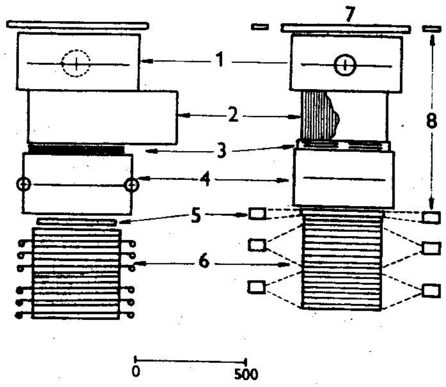

Fig. 1. The basic diagram of the experimental apparatus BFB-S. 1—4 spark chambers, 2 — emulsion stack, 3 — horizontal layers of nuclear emulsion (layers B), 5 — scintillation detector CC-2, 6 — ionisation calorimeter, 7 — scintillattion detector CC-1, 8 — photomultipliers.

Besides, materials for photographing-life, nuclear photoemulsions and an X-ray film were placed in ionisation calorimeter.

The whole weight of the apparatus was 1200 kg.

A more detailed description of the apparatus and the character of its work are presented in [1, 2].

The trajectory of the satellite was nearly circular with an inclination of 51° to the equatorial plane. After 4 days in space the satellite landed on the Earth.

After a corresponding processing of nuclear emulsions (sticking onto glass, marking, film processing, exact cutting of the photographic plates into sizes of 20 × 10 cm) the scanning of high energy particle interactions in nuclear photoemulsion followed. The interactions were observed in the following way:

From pictures of spark chambers the coordinates and the direction of the shower issuing from the emulsion stack were obtained. According to these coordinates the searching for showers was made in layers of nuclear photoemulsion placed under the emulsion stack (in layers "B", see Fig. 1). Using the exact geometric connection of layers "B" to the emulsion stack, the observer found the same shower in the individual layers of the stack and proceeded in the direction of the shower, up to the primary particle interaction.

Thus, 75 interactions of high energy particles were found. It was shown that the probability of finding the shower according to spark chambers data in the conditions of our experiment was about 0.7. In interactions accompanied by an energy deposition in the upper section of the ionisation calorimeter greater than 2×10^{12} eV, the probability of finding the shower was equal to 1.

The probability W_{s1} of finding the random shower according to the given coordinates was estimated, the shower not corresponding to that primary particle which had deposited energy in the ionisation calorimeter. It turned out that $W_{s1} \leqq 0.022$.

Among the interactions found in this way there were 17 events, where the primary particle was a nucleus with a charge of $Z \geqq 6$.

In every interaction of nucleus and heavy fragment (if here was one) the charge was determined by the method of slow δ-electrons. For each interaction the number of shower particles n_s and the angles of their emission were determined, as well as the number of α-particles and the number of protons of fragmentation — n_α and n_p and the corresponding number of grey and black tracks — N_h.

The energy of the nucleus was established either according to the angle of emision of the α-particles of fragmentation (if there were any) or by the method of Castagnioli. It was possible to determine the lower limit of the primary particle energy according to the energy deposited in the ionisation calorimeter.

Physical characteristic of nucleus-nucleus interaction is number of produced particles related to one interacted nucleon, i. e. value $n=(n_0-n_p)/\nu$, where ν-number of nucleons of impacting nucleus, taking part in given interaction.

The number of interacting protons ν_p was determined from the relation

$$\nu_p = Z_0 - (Z_1 + 2n_\alpha + n_p)\,,$$

where Z_0 and Z_1 are charges of the primary nucleus and of the fragment.

It is natural to assume that the average number of interacting neutrons is equal to the number of interacting protons. That is why we took $\nu = 2\nu_p$. In these interactions where $\nu_p = 0$ we put $\nu = 1$.

In determination of ν the least defined is the procedure of the fragmentation protons distinction, because they have no external symptoms with the help of which it is possible to distinguish them from other shower particles.

In case of the primary nucleus energy being known, it is possible, with the given value of fragmentation protons energy in the system of the primary nucleus — E_p, to obtain the maximal angle $\theta_{max} = \mathrm{arctg}\,[(1/\gamma_0)\,(\beta/\sqrt{1-\beta^2})]$ of fragmentation protons defining the interval of possible emission angles in laboratory system.

In the case when we suppose all particles with angles $\theta \leqq \theta_{max}$ of emission to be fragmentation protons, we may only overestimate n_p and underestimate the value of ν.

Among interactions found according to the calorimeter data there were cases when the nucleus or its heavy fragment, due to interaction, emitted few α-particles of fragmentation, according to which it was possible to determine the γ-Lorentz-factor of the primary nucleus. It is evident that all the preceding and following interactions in a given chain of successive interactions (if there are several) will have the same value of γ_0.

Because of this we chose for the following analysis only such interactions for which it was able to determine γ_0 according to the α-particle of fragmentation. The number of such nuclei was 5. In the emulsion stack they caused 10 interactions in which together 233 shower particles were created of.

Characteristics of interactions of these nuclei are given in Table 1.

Table 1

Number of event	K	ε GeV/amu	Z_0	Z_k	Σn_s	Σn_p	Σn_α	$\Sigma(n_s - n_p)$	$\Sigma\nu$	$\Sigma\nu\mapsto_{\otimes\otimes}$
2084	1	380	6	0	2	0	3	2	1	9 ± 5
2553	2	460	16	0	14	1	4	13	14	132 ± 18
2797	3	90	22	0	100	5	3	95	22	134 ± 14
2952	2	310	8	0	20	2	2	18	4	35 ± 9
3135	2	170	23	0	97	2	4	95	26	200 ± 10
					233			223	67	510 ± 31

Notations used in the Table: K — number of interactions of a given nucleus in the emulsion stack; ε — energy of the nucleus per nucleon in GeV; Z_0 — charge of the primary particle, Z_k — charge of the fragment after the k^{th} interaction; Σn_s, Σn_p, Σn_α — total number of shower particles, protons and α-particles of fragmentation, corresponding to all the interactions of the given nucleus; $\Sigma(n_s - n_p)$ — total number of shower particles besides protons of fragmentation created in all the interactions of the given nucleus; $\Sigma\nu$ — total number of interacting nucleons in all the interactions of the given nucleus, $\Sigma\nu n_{pp}$ — the expected number of shower particles, which would be created in $\Sigma\nu$ independent pp-interactions with the energy ε GeV.

From the Table we can see that as a result of 67 interactions of nucleons "covered" in the nuclei, 223 particles were created, i. e. the average multiplicity per one interacting nucleon is equal to $\langle n \rangle = 223/67 = 3.3 \pm 0.7$.

If in the analysed cases of nuclei interaction with nuclei the interactions were the sum of independent nucleon-nucleon interactions, then 510 particles must have been created, i. e. the average multiplicity per one interacting nucleon should be equal to $\langle n \rangle_{pp} = 510/67 = 7.6 \pm 0.5$.

The obtained result of low multiplicity per one interacting nucleon "covered" in the nucleus is not a speciality of our choice of nuclei. We obtained a similar result also using the other interactions (regardless of less accuracy in the determination of the choice of fragmentation protons).

From the given data it can be seen that the low multiplicity of created particles per one interacting nucleon is not a result of statistical fluctuations, but it reflects a process of a not independent summation of nucleon interactions, when the nucleons are covered in the nuclei. Such a process of collective interactions is according to our data not always realized, but with a sufficient high probability.

We wish to remark that similar interactions with a low multiplicity per one interacting nucleon are presented in the quoted literature [3, 4].

REFERENCES

[1] *Collaboration of the IK-6 experiment, Cosmic Ray Investigation Experiment on Board the AES "Intercosmos-6"*, Izv. AN SSSR, ser. fiz. *37* (1973), 1386.
[2] Brikker S. I. et al., Izv. AN SSSR, ser. fiz. *38* (1974), 930.
[3] Rybicki K., Nuovo Cimento *28* (1963), 1437.
[4] Abraham F. et al., Preprint EFJNS 65—44.

Received March 17th, 1977