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Investigation of unusual phenomena in cosmic rays with *Tien Shan* and *Pamir* experimental setups at energy higher than 1 PeV - II(*)

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Summary. — The project of upgrading of the *Pamir* and the *Hadron* experimental setups currently operating at high mountain altitudes is proposed. The setups are designed for comprehensive investigations of the primary cosmic rays (PCR) as well as nuclear interactions in the energy range 1–1000 PeV where some new phenomena beyond the conventional conceptions of nuclear cascade processes have been recently observed.

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1. – Main goals of experiments with the *Pamir* and the *Hadron-M* experimental setups

At present, a dramatic situation exists in cosmic ray physics at energies above 1 PeV. On the one hand, numerous phenomena beyond the conventional concepts of nuclear cascade processes in the atmosphere are observed mainly in the EAS core region. On the other hand, modern accelerator experiments still provide no evidence for any serious deviations from the Standard Model of strong interactions [1].

One may suppose that unusual particles, *e.g.*, strangelets or even more exotic ones may be present in the PCR flux at energies above several units of PeV and their existence could be the origin of the observed anomalous phenomena in experiments with cosmic rays.

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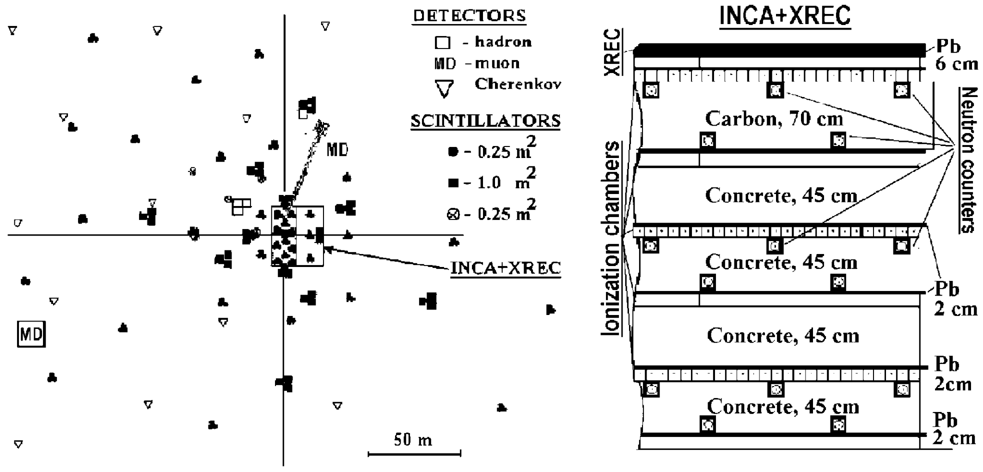

a) b)

Fig. 1. – a) A layout of detector location of the *Hadron-M* setup at Tien Shan (3340 m a.s.l.). b) Dissection of the central detector of the *Hadron-M* setup.

To promote this study we propose to perform a series of experiments which could considerably contribute to the solution of this dramatic situation. These experiments are necessary not only to increase the statistics of anomalous events but also to improve the reliability and variety of experimental data on each of the events. With this object in view, we intend

– to employ an X-ray emulsion chamber of a new type specially designed for certain physical problems at the Pamirs in the framework of the *Pamir-Chacaltaya* experiment;

– to upgrade the setup which is now in operation at the Tien Shan Mountain Station. The main point of this upgrading which will result in assembling a new *Hadron-M* setup is the employment of a radically new detector, namely, a ionization neutron calorimeter (*INCA*) of large area.

The idea to associate ionization calorimeter and neutron supermonitor in one device (*INCA*) by including neutron counters with neutron moderators in the calorimeter was proposed ago by Dr. A. P. Chubenko [2]. This technique essentially enlarges the range of measured energies, improves the accuracy of energy determination and makes it possible to separate primary particles of electromagnetic origin from nuclear ones by neutron number in a single cascade. The validity of the assumptions was confirmed by accelerator experiments with stretching beams of 70 GeV protons and with 3 GeV pion beams as well as with 550 MeV electron beams.

2. – The present status of the *Hadron* setup and its upgrading

The *Hadron* setup consists of the following detectors and instruments (fig.1a):

– In the center, there is an XREC with ionization chambers of 160 m^2 in sensitive area. A correlation with EAS is established by coincidence of space coordinates and angular characteristics of electron-photon cascades in XREC with those signals detected by ionization chambers positioned in a cross-way manner. The ionization chambers measure also the sum energy of electron-photon component distributed over the whole area of the XREC. The spatial resolution of ionization channels is 0.11 by 0.11 m^2.

– The ground surface shower array of 120 scintillation detectors for recording EAS electron-photon component. The arrangement of the detectors make it possible to record EAS inside a circle of 200 m in radius positioned in the center of the setup and thus to refine lateral distribution functions (LDF) at large distances.

– The *Chronotron* system for determination of EAS arrival angles by measuring the delay of the EAS front arrival in various points of the shower array.

– Fifteen spectrometers of complete absorption on the basis of ionization chambers for measuring the energy flux of the electron-photon component; these detectors are regularly distributed within a circular area of 40 m radius.

– Underground central muon detector of 100 m^2 sensitive area for recording muons with energy $E_{\rm m} > 5$ GeV.

– For measuring direction and time of arrival of single muons with respect to EAS front, there is a *MUON-T* central underground setup consisting of 18 wide-gap spark chambers with nanosecond electronic recording channels.

– The neutron supermonitor 18 NM-64 located at 34 m from the center and connected with the EAS recording system for measuring the energy flux of the hadron component with $E_{\rm h} > 50$ MeV.

– The *VEGA* system consisting of 13 photomultipliers without mirrors for recording EAS Cherenkov radiation in the atmosphere.

The main trends of upgrading of the *HADRON-M* central part are as follows:

– Replacing the existent old-type ionization impact recording facility in the central part of the *Hadron* setup with the INCA (fig.1b).

– Replacing the old-type electronics with modern one.

3. – Statistics within 3-year exposition of the *Hadron-M* setup and expected results

The problems which could be solved as a result of 3-year exploitation of the *Hadron-M* setup are listed beneath with short description of the applied techniques for their solution:

1) The conclusion of the diffusion model on the nature of the PCR energy spectrum bend at energy of 3-4 PeV will be confirmed or rejected. For this purpose, the partial energy spectra for the main PCR nucleus groups (protons, α-particles, middle nuclei with $Z = 6$–8, heavy nuclei with $Z = 10$–25 and iron nuclei) in the energy range 0.5–100 PeV, *i.e.* in the range before and above the first energy bend, will be determined for the first time.

The total number of recorded EAS with axes within the INCA borders will be as high as $\sim 10^5$ events after 3-year setup operation term. For all such events, the EAS energy will be determined by the most reliable method as an integral of energy densities released in the setup detectors by each of the main EAS components, *i.e.* electron-photon, muon and hadron one. The expected accuracy of the EAS energy determination is 10–15% while the expected uncertainty in the primary energy is $\sim 30\%$ assuming the validity of the Standard Model of hadron interactions. The nature of primary particle for each particular event can be established from the collection of several EAS characteristics and, in some cases, it can be determined using the characteristics of the corresponding gamma-family recorded by XREC [3]. To reconstruct the mass composition of PCR particles from the characteristics of induced EAS we shall apply the technique of an inverse problem solution and multivariate analysis [4] exploited for image recognizing. We might expect that the reliability of attribution of recorded events to the specified five groups of PCR particles will be high enough and an error of nucleus nature determination will be within 20–30% due to high mountain elevation of the setup. The expected numbers of events for each specified group of PCR particles will be near 10^4.

Thus the information on existence of PCR partial spectrum bends will be originally obtained in the experiment. The comparison of these data with predictions of various diffusion model versions will make it possible to draw conclusion on applicability of the model version under consideration. In any case such an information will clarify not only the spectrum bend nature but perhaps the existence of some cosmic ray source nearby the Galaxy which can produce irregularities in the PCR composition around the Earth.

2) The search for local gamma-ray sources and the study of diffuse gamma-radiation in a weakly explored energy range of 0.2–10 PeV will be performed. For this purpose, intensity and shape of energy spectrum of muon-less, hadron-less and, especially, neutron-less EAS will be measured in the specified energy range. The performed accelerator experiments and appropriate estimations give the value of coefficient for rejection of hadron induced showers as low as 10^{-5}.

In the 3-year term of *HADRON-M* operation, it is expected to observe 1200 EAS in the 0.2–10 PeV energy range. It will be possible not only to discover the source of primary gamma-quanta but also to determine their energy spectrum.

Besides, the flux value for the primary diffuse gamma-quanta with energy higher than 200 TeV will be established.

3) Unique information on unusual phenomena and events previously observed in cosmic rays will be obtained due to EAS recording both in the calorimeter and by scintillation and neutron counters; this makes it possible not only to measure the primary energy E_0 reliably and accurately enough but also to effectively determine the nature of the primary particle producing each of the event.

Such information may be crucial for interpretation of the following formerly observed unusual events:

a) Events with coplanar divergence of secondary particles of highest energies. At EAS energies above 10 PeV, the total number of 4-core coplanar events will be about 10. It is significant that, for all these events, a complete information will be obtained both on the primary particle generating the EAS and on the properties of the EAS itself. Besides, a few dozens of 3-core coplanar events in multi-core EAS will be observed.

b) Events related to production of "halos", *i.e.* large diffuse darkened spots on X-ray films produced by high-energy hadrons. The expected number of these events will amount 25 ± 5. Note that information on the primary particle nature and its energy is of particular importance for interpretation of these events. More over, it is hard to exclude that the nature of these primary particles is unusual, namely, it may be related to production of strangelets. In this case, the corresponding EAS will have also unusual characteristics. For instance, they will produce extended hadron shower cores in the deep calorimeter [5].

c) In the *HADRON-M* operation term we expect to detect several Centauro and Anti-Centauro events, but their recording will be supplied with information of main importance, *i.e.* primary particle nature and its energy. Perhaps the energy threshold for their observation is higher than available at accelerators.

d) Knowledge of nature of the primary particle will make it possible to perform

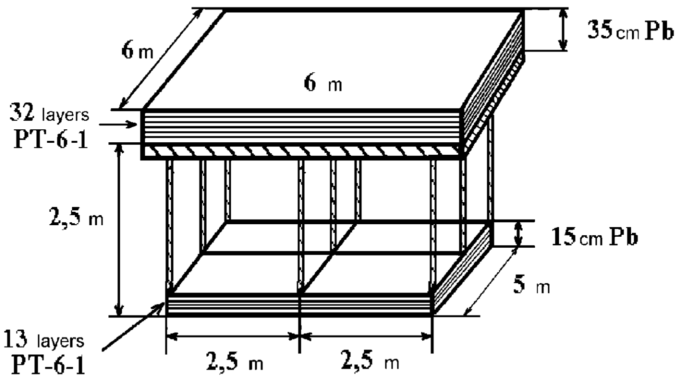

Fig. 2. – The *Pamir* XREC designed for the study of penetrating particle absorption.

detailed analysis of EAS characteristics in order to discover the signature of quark-gluon plasma in heavy nuclei interactions (*e.g.*, Fe-air).

e) Physics processes responsible for appearance of abnormally delaying for 500 and more microseconds intensive neutron component in EAS cores originated from primary particle with energy higher than 3 PeV will be established.

4) The problem of existence of the second ("reverse") bend in the PCR energy spectrum at energies higher than 50 PeV will be solved. The expected number of EAS with energies higher than 50 PeV drastically depends on the presence or absence of the second bend and will amount to 600 and 200, respectively, after 3 years of operation.

4. – XRECs of the *Pamir* Experiment: status, upgrading and expected statistics

An extensive experimental site destined for exposition of large-area XREC at elevation of 4370 m above sea level at the Pamirs was constructed by the *Pamir Experiment* Collaboration in the past years (fig. 2).

At present a steel frame 36 m^2 in area is constructed at Pamirs. The frame makes it possible to assemble an XREC consisting of two lead blocks separated in the vertical direction by 2.5 m air gap. The total depth of lead absorber amounts to 50 cm. If the effect of weak absorption arises from charmed Λ_c and D-meson production, the corresponding absorption curve which is expected after 3-year exposition must have a clear bump.

The absence of the bump will favor the presence of a new type of hadrons with production cross-section about one order less than nuclear one. It is quite evident that the discovery of such particles, probably consisting of quarks of higher color symmetries, would be of fundamental importance for physics.

In conclusion, we are glad to invite all cosmic ray physicists to take part in these experiments with the *Pamir* and *Tien Shan* setups.

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