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HADRON-55 complex setup for study of hadron interactions within the central part of EAS cores

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A new project is proposed in order to obtain direct data on the value of charmed-particle production cross section in interactions of cosmic ray hadrons on lead nuclei at average energy $E_h \approx 75$ TeV in the forward kinematic cone and to determine a contribution of prompt muons to the overall flow of superhigh energy muons within EAS at mountain altitudes. The experiment will be carried out at the Tien Shan High Mountain Research Station (TSRS) located at an altitude of 3340 m a.s.l. It will clarify the nature of weakly absorbed hadronic component of cosmic rays (so-called "long-flying component"), which was previously observed in a number of experiments with cosmic rays including those performed at the TSRS. Besides, anomalies and nearby sources of superhigh energy PCR will be searched within the experiment by scanning the celestial sphere and applying a high-sensitive difference method. To achieve these objectives, a new "HADRON-55" hybrid setup representing a two-storey coordinate calorimeter of 55 m^2 in area and 1050 g/cm^2 deep is planned to assemble on the basis of the previous "HADRON-44" hybrid calorimeter and two-storey X-ray emulsion chamber (XREC). The hybrid calorimeter and adjacent territory will be covered with a dense array of scintillation detectors.

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1. Introduction

Quite often forgotten that particle physics has originated from cosmic ray physics. After splendid results of particle physics thanks to accelerator technique advances we are again witnessing some interest to super high energy cosmic ray studies due to some new effects observed at energy range above 10^{15} eV which are hard to explain within the conventional processes governed by Standard Model. These new phenomena observed in cosmic ray experiments can be accounted for by production of new particles or by new interaction mechanisms. The main types of the unusual phenomena in cosmic rays at energies greater than 10^{15} eV are as follows:

- the problem of the PCR energy spectrum "knee" at energy $E_0 \sim 3 \cdot 10^{15}$ eV;
- the cut-off of the primary cosmic ray spectrum at energy $E_0 \sim 3 \cdot 10^{19}$ eV;
- the appearance of so-called Centauro- and Anti-Centauro types of events with abnormal ratio of charged and neutral hadrons out of conventional statistical fluctuations;
- the abnormally high fraction of so-called "halo" events observed with XRECs which contain a diffuse macroscopic spots on X-ray films characterized by high energy flux (~ 20 TeV/mm^2);
- the alignment of super high energy ($\sum E_{visible} \geq 700$ TeV) gamma-ray$-$hadron families characterized by an alignment of tracks of the most energetic particles along a straight line;
- the so-called long-flying particles with abnormally weak hadronic absorption violating conventional exponential dependence.

It is worth noting that some indications to existence of the alignment effect, first observed in the *Pamir* XREC experiment [1], were recently obtained at collider experiments, i.e., RHIC and LHC, where so-called "ridge" effect manifesting strong azimuth anisotropy was discovered [2, 3]. These effects have been recently described with a bright and spectacular model of "crystal world" employing a concept of latticized and anisotropic spatial dimensions [4].

Overall, however, it has not yet found any substantial deviations of collider experiment results from Standard Model predictions concerning hadron interactions while there are several new cosmic ray phenomena observed mainly in the extensive air shower (EAS) cores generated by PCR particles with $E_0 \geq 10^{15}$ eV in the atmosphere. This contradiction is rather illusive if you take into account that parameters of EAS core region under study in cosmic ray experiments with hadron calorimeters (namely, its characteristic radius is ~ 10 m and the height of the first interaction point of the primary particle generating an air shower above the observation level is about $20 - 30$ km) correspond to pseudorapidity region $\eta \sim 12$ which is practically inaccessible in collider experiments due to specific constructive restrictions imposed on the positioning of detectors around the vacuum pipes. Thus the cosmic ray experiments provide us with complementary data on hadronic interactions as compared to collider ones.

Besides, high energy cosmic ray flux at energies above 10^{15} eV may probably contain unusual particles, e.g., strangelets, which could give rise to the abnormal phenomena observed in cosmic ray experiments but are absent or could not be detected in accelerator experiments due to their properties. This year we have started a new cosmic ray experiment at the Tien Shan High Mountain Research Station (TSRS) located at an altitude of 3340 m above sea level 45 km far from Almaty city where we have assembled a new HADRON-55 hybrid setup consisting of a two-storey coordinate scintillation-ionization calorimeter (CSIC) of 55 m^2 in area and a dense array of scintillation detectors which cover the calorimeter itself as well as the adjacent territory.

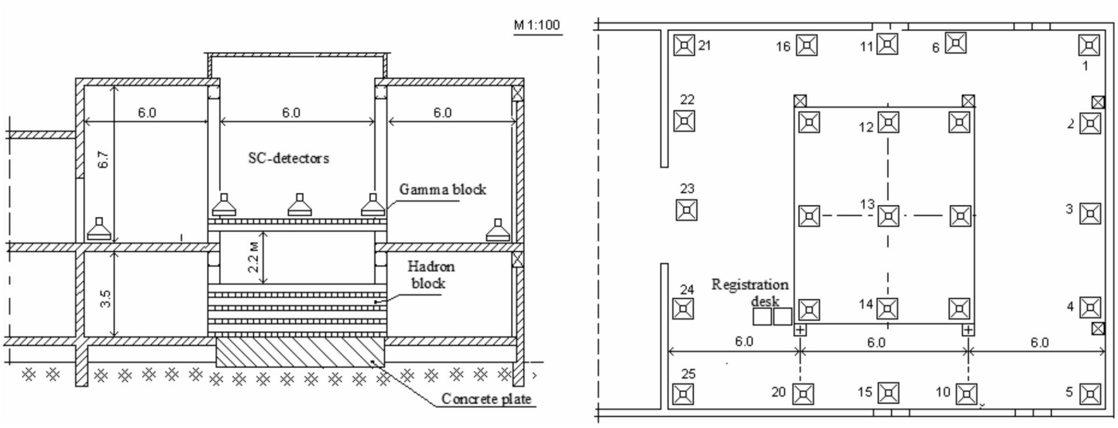

Figure 1: (left) Location of the two-tired coordinate scintillation-ionization calorimeter inside a two-storied laboratory building (a side view). (right) Location of scintillation detectors at the top and around the calorimeter inside the laboratory building (a top view).

The hybrid calorimeter was assembled on the basis of the previous HADRON-44 hybrid calorimeter [5] and two-storey XREC [6].

The main goal of the launched project is to clarify the nature of weakly absorbed hadronic component of cosmic rays (or so-called "long-flying component"), which was previously observed in a number of experiments with cosmic rays including those performed at the TSRS [7, 8].

The main advantages of the constructed HADRON-55 setup are a possibility to determine the energy of the primary radiation as well as its capability to measure the angular, lateral and longitudinal distribution of secondary particles in the atmosphere and in the lead absorber. It is also very important that the setup makes it possible to study different components of air showers thus providing experimentalists with comprehensive information on the studied phenomena.

2. The HADRON-55 setup design

The complex setup is housed in a building area of 324 m^2 and a height of more than 10 meters. The setup layout is presented in Fig. 1.

The HADRON-55 setup represents a two-tiered coordinate scintillation-ionization calorimeter (CSIC) of 55 m^2 in area and 1050 g/cm^2 deep (Fig. 2) surrounded by a dense array of scintillation detectors which will be extended in future outside the laboratory building and will cover an area of more than 2 km^2.

The tiers are spaced vertically by 2.2 meters. The upper deck contains a standard XREC (so-called Γ-block) and two rows of ionization chambers (IC) under it, which are arranged in mutually perpendicular directions. Beneath them, there is a target lead block 22 cm thick in which hadrons of cosmic radiation interact effectively with lead nuclei. The design of the upper tier installation makes it possible to determine the energy of electron-photon component and, in conjunction with the lower tier ("hadron" block) enables experimentalists to reconstruct the particle trajectories. There are also 24 scintillation detectors 0.25 m^2 each which are spread over an area of 324 m^2 at the level of the upper tier.

The lower tier combines the XREC and the underlying ionization calorimeter, which consists of iron absorber with gaps where ICs, neutron and Geiger counters are placed. This unit is used to measure the energy of the charged cosmic ray component as well as to determine the particle trajectories. The specific feature of the HADRON-55 setup is that it represents a set of different detectors thus allowing a much more detailed study of characteristics of cosmic ray particle interactions.

According to [9] and our calculations [5] the error in determination of interaction energy in an ionization calorimeter of 1,000 g/cm^2 thick containing six levels of registration is about 10%.

Therefore the design of the calorimeter has 9 rows of detectors and the total thickness of the absorber is 1033 g/cm^2 that is sufficient for a correct determination of the primary particle energy E_0 with a reasonable accuracy.

While scintillation detectors and ICs measure the coordinates of the EAS particles with a precision of $\Delta x,y \sim 0.5$ m and ~ 10 cm, respectively, the lateral resolution of XRECs is as high as ~ 100 microns. The accuracy of the particle energy determination in XREC experiments is also rather high, i.e., $\Delta E/E \sim 25\%$. However, each X-ray film accumulates a large number of events during XREC exposition (about one year) and thus not an easy problem of separation of genetically unrelated events occurs when scanning and processing experimental data. Another problem you are to solve with combined technique is matching of EAS events registered by electronic detectors continuously in real-time regime with XREC events accumulated by films for a long period of time.

In spite of considerable complexity in operation and high cost of detectors with electronics (scintillation detectors, ICs, neutron counters, etc.), they have a great advantage over the XREC technique since they record events continuously with reliable separation in time. We believe that the most promising direction in development of technique of cosmic ray interaction studies is a hybrid technique (XREC + EAS) which combines advantages of both techniques.

It is envisaged that, in the nearest future, the HADRON-55 setup will work as a part of a new shower array which is now under construction at TSRS. This array represents a network of scintillation detectors located on an area of about two km^2. Thus, measurements of the primary particle energy E0 and determination of their mass be carried out more reliably that makes it possible to solve the problems planned.

3. Ionization chambers used in the CSIC

The upper tier of the CSIC (i.e., Γ-block) consists of two rows of ICs arranged in mutually perpendicular directions. The first row contains 100 ICs and the second one comprises 144 chambers of size $300 \times 11 \times 6$ cm^3 each. The signal read-out of each IC is performed with in-house electronic recording channel developed and fabricated in TSRC.

Fig. 3 presents a schematic block diagram of a recording channel of the ionization chamber employing the 544UD1 chips of operational amplifiers and the SMP04 cell of analog memory. At the input of the amplifier, there are diodes D1 and D2, which limits the input voltage and partially compress the input range to a logarithmic scale. In the feedback circuit of the output cascade of the amplifier at the 544UD2 chip, a diode is also installed which provides a quasi-logarithmic transfer characteristic of the amplifier. The amplifier of ionization chamber makes it possible to boost signals from 100μV up to 100 V that means that it has a dynamic range (gain) of 10^6.

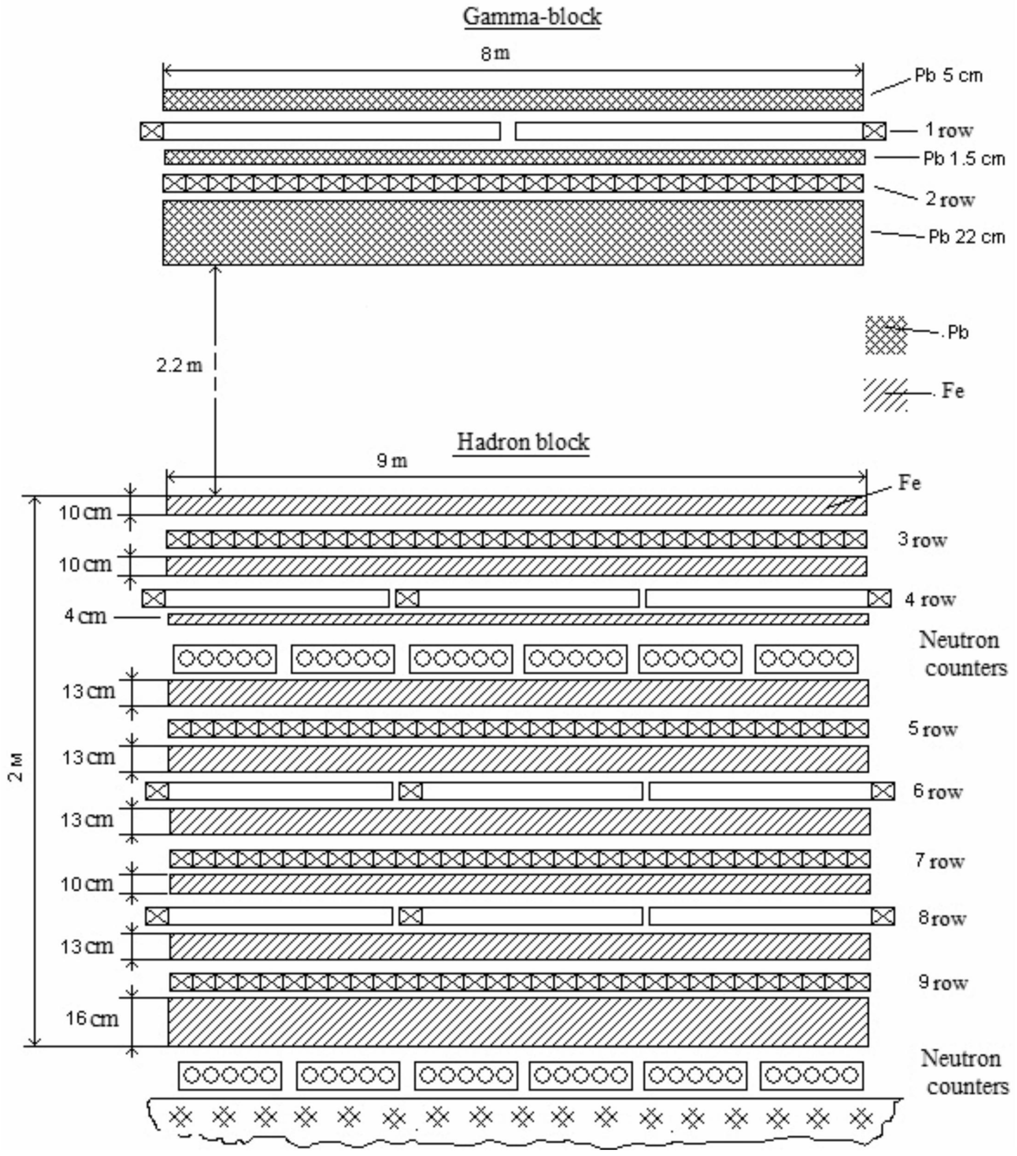

Figure 2: A two-tiered coordinate scintillation-ionization calorimeter of the HADRON-55 setup.

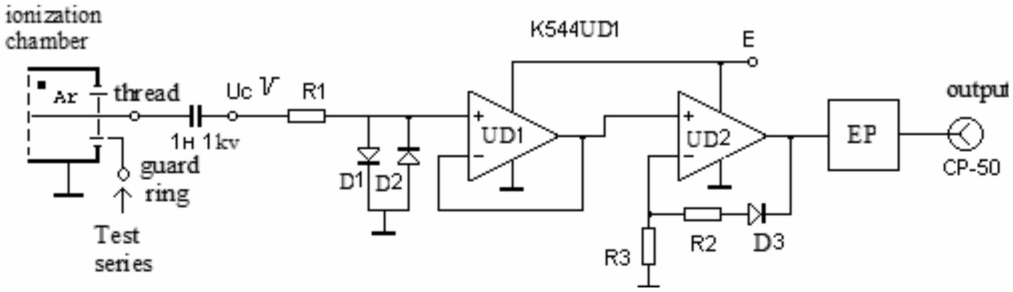

Figure 3: A schematic block diagram of the logarithmic amplifier of an IC recording channel.

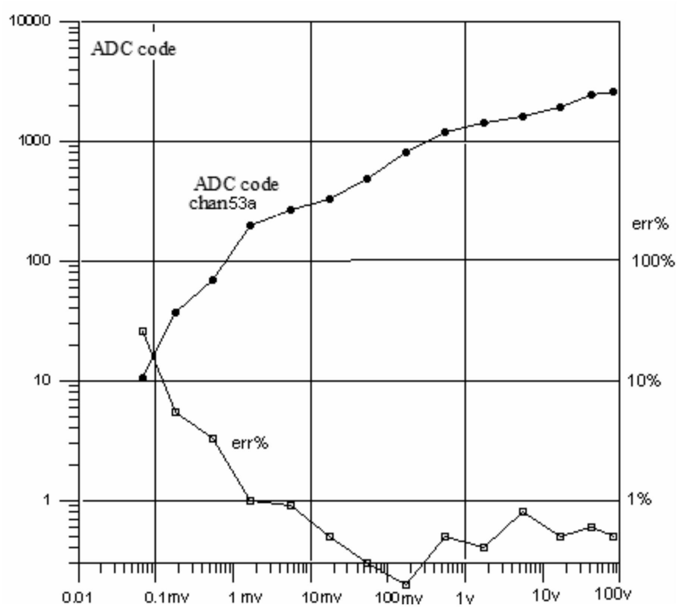

Figure 4: Transfer function of the amlifier of ionization chamber.

4. Scintillation detectors used in the CSIC

To detect electron EAS component, the HADRON-55 setup uses scintillation detectors fabricated on the basis of solid plastic scintillators which contain luminescent substances emitting light when charged particles pass through them. The light pulses are recorded by a photomultiplier tube (PMT-110 in our case). Fig. 5 shows the structure of the scintillation detector.

A light-tight casing of the scintillator is made of an aluminum sheet of 1 mm thick and is covered inside with white reflective paint. In the lower part of the casing, there is horizontally mounted plastic block of 50×50 cm^2 in size and 5 cm thick. The upper part of the body has the shape of a pyramid on top of which a photomultiplier is mounted together with a voltage divider for dynodes and a PMT signal amplifier. At present, 24 scintillation have been installed and are already under operation.

5. Neutron detectors of the CSIC

The method of energy measuring based on the detection of evaporated neutrons from the nuclei splitting produced by cascade particles was proposed about 60 years ago [10] and is used in analyzing the data of the world network of neutron monitors [11]. However, neutron calorimeters have not yet been widely used. Our project by using a two-tiered SCIC combines two different methods of particle energy measuring, i.e., the ionization calorimeter method and that of the neutron one. The informativeness of such a combined calorimeter is substantially higher as compared with ionization and neutron calorimeters individually [12].

Indeed, in addition to determining the energy of two independent methods, SCIC is able to separate gamma rays, electrons and hadrons in the mixed flux of particles due to the fact that the relative neutron yield in electromagnetic cascades as compared with nuclear ones is not more than

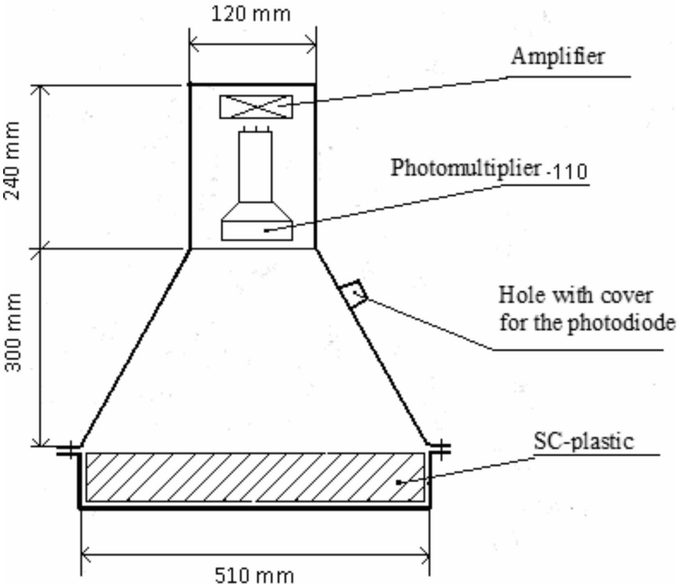

Figure 5: The design of the scintillation detector.

5 – 10% [13, 14]. When neutron moderation to thermal energies is used for neutron detection, the design of the CSIC is practically the same as of common calorimeters. In this case, the signals from the neutrons will be delayed with respect to the ionization signal to tens or hundreds of microseconds because of thermalization and diffusion processes in the material of the moderator and, thus, the detection of ionization and neutron signals can be carried out by the same detectors, such as gas proportional neutron counters, with some time shifting .

The CSIC has two rows of neutron detectors. The first one is between the third and fourth registration rows, and the second one is just after the 9th row (see Fig. 2). This arrangement of neutron detectors allows to determine independently the primary particle energy [15], number of neutrons and their lateral distribution function in the calorimeter.

6. The trigger and the readout systems

The HADRON-55 setup trigger system assumes selection of events by several EAS parameters: total ionization, density of charged component, position of the EAS axis (hitting parameters), etc. The event registration is done by recording detector signals in a computer memory according to a special control (trigger) signal which is generated in a special electronic unit of the setup.

It is supposed that the triggers system of the setup will have four different modes. However, nowadays we use only the 1st mode of trigger system operation based on the circuit processing the sum of ionization in two detection levels (rows) of the Γ-block.

The readout system includes a computer and a software package of management, control and processing. The program manages the readout process through the computer's LPT parallel port, then through the CAMAC data controller which transfers data to the computer memory from the ADC modules installed in the CAMAC crate. With the accumulation of events in the computer memory, the database is formed.

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