«Hadron-M» Complex Installation

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cosmic rays ionization-neutron calorimeter scintillation detector

1. «Hadron-M» Complex Installation

For decades, the Institute of Physics and Technology has been conducting research in the field of cosmic ray physics using experimental data from ionization calorimeters. The initial studies started with the "Hadron-9" [1][2][3] calorimeter with an area of 9 m^2; after modernization, this installation changed its structure and area size. The next calorimeters were "Hadron-44" [4][5] with an area of 44 m^2, and "Hadron-55" [6][7][8] with an area of 55 m^2. All installations have been located at an altitude of 3340 m above sea level.

The upgrade of the ionization-neutron calorimeter "Hadron-55" expanded the area of research by increasing the thickness of the absorber of the installation. The thickness of the calorimeter includes two new rows of ionization chambers with iron absorbers. Two shower systems were added, the first one above the calorimeter and the second peripheral shower system around the calorimeter, in order to increase the statistics of the studied particles of cosmic radiation. The calorimeter and internal shower system are located in the laboratory building with an area of 324 m^2. An external shower system is installed outside the building along concentric circles with radii of 25, 40 and 100 m, 4 SDs for each circle. The main difference of this calorimeter from the previous similar installations is the added number of neutron counters for registering neutron fluxes resulting from the development of extensive air showers.

In connection with the reconstruction, a new name was assigned—"Hadron-M complex installation", which included an ionization-neutron calorimeter with an area of 55 m^2 and an absorber thickness of 1244 g/cm^2 (out of eight rows of ionization chambers), one row of neutron detectors and two shower systems of scintillation detectors. The effective area of the "Hadron-M" complex installation was about 30,000 m^2 [9].

Figure 1 shows the layout of the external storm water system of the "Hadron-M" complex installation.

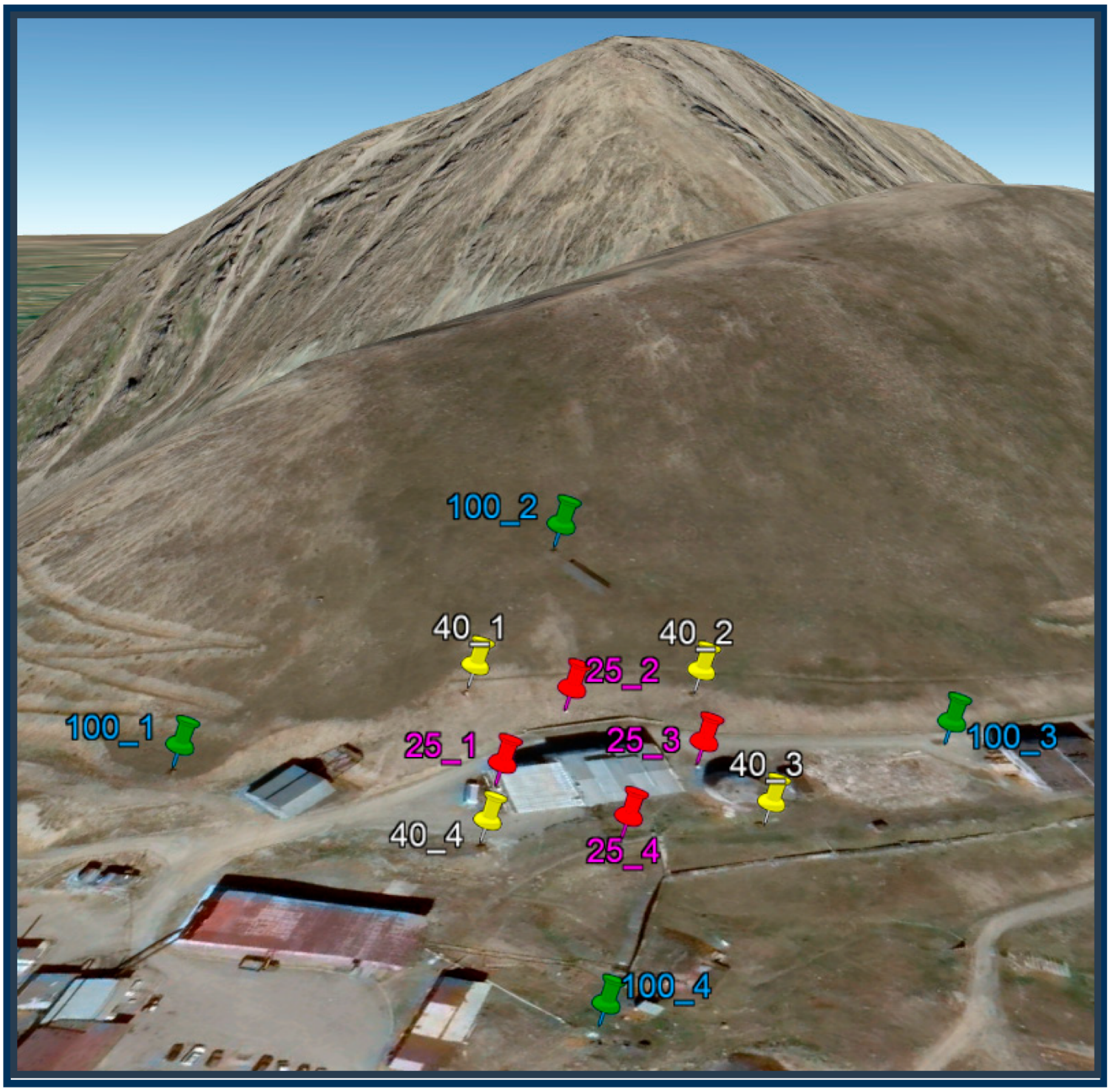

Figure 1. A snapshot of the location of the external storm system of the complex installation “Hadron-M”.

The snapshot shows three-color marks (red, yellow, green) indicating the location of the SDs around the calorimeter (rectangular depression). Each label has numbers that show the distance from the center and the number of a detector (for example, 40_1 means 40 m from the calorimeter and 1 is the number of the SDs).

2. Ionization-Neutron Calorimeter

Currently, an improved series of a new computerized detector of hadron interactions of cosmic rays, the ionization-neutron calorimeter, has been put into operation. The calorimeter is designed to detect the most energetic hadrons and gamma rays in EAS systems. Studies and analysis of the data of each individual interaction recorded by the calorimeter detector system make it possible to obtain the primary energy of cosmic radiation particles, as well as the angular, spatial and depth distributions of secondary particles that characterize the main parameters of the shower. The new structure of the installation will make it possible to study the most central part of the forward kinematic cone of extensive cosmic ray air showers [9].

The ionization-neutron calorimeter includes an internal shower system of 30 SDs detectors and 1200 ionization chambers, which make up eight rows located in mutually perpendicular directions and one row of neutron counters. Taking into account the area of the calorimeter and the adjacent infrastructure (30,000 m^2), which would increase significantly in the future, it can be expected that the number of interactions with energies above ~10^{15} eV would be more than 50,000 events per year. The peculiarity of the calorimeter is that it represents a set of various detectors, allowing for the more detailed study of the characteristics of interactions of particles of cosmic radiation, accurate calculation of the measurement of EAS arrival angles, and the development of the EAS core along the depth of the calorimeter.

Figure 2 demonstrates a diagram of a two-level ionization-neutron calorimeter: the upper level is a gamma block, the lower level is a hadron block.

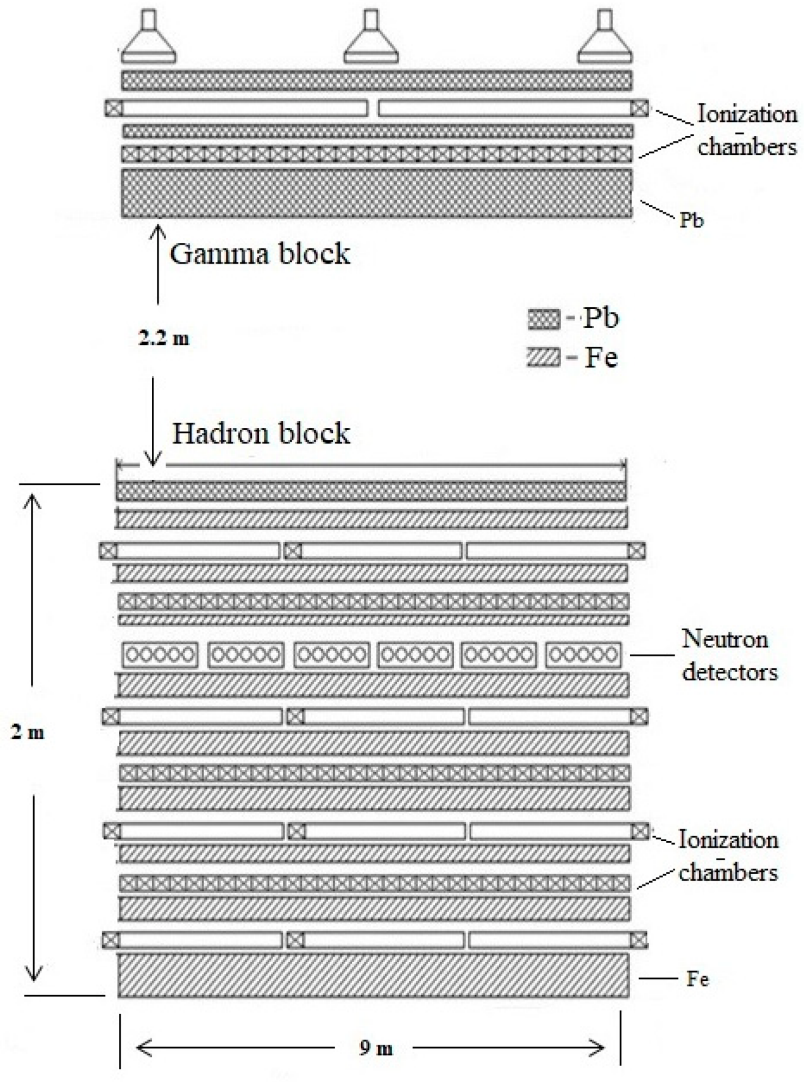

Figure 2. Scheme of the ionization-neutron calorimeter.

The first two rows of the gamma block contain 238 ionization chambers, of which 100 chambers are in the first row and 138 chambers are in the second. Each row is separated by lead absorbers with a total thickness of 26.5 cm or

310 g/cm^2 (see **Figure 2**).

Figure 3 shows a snapshot of the gamma block, above which the internal shower system of SDs detectors is located. The shower system contains 30 detectors at a distance of approximately 1.0 m from each other with an occupied area of 320 m^2, nine of which are located in the gamma block.

Figure 3. Gamma block with internal shower system of the SDs detectors of the ionization-neutron calorimeter.

The hadron block of the calorimeter contains 870 ionization chambers, which are placed in six rows. One row, which is located after the first pair of ionization chambers, contains neutron and Geiger counters. This row records and detects neutrons to obtain information about the properties of nuclear interaction at high energies, in particular, to detect neutron fluxes resulting from the development of EAS. Each row is separated by an iron or lead absorber (see **Figure 4**).

Figure 4. Hadron block of the ionization-neutron calorimeter.

All rows of ionization chambers (from rows 1 to 8) are mutually perpendicular. The width of the ionization chambers is 11 cm. A pair of mutually perpendicular rows form the observation level (more precisely, they give the X, Y coordinates of the passage of particles). This makes it possible to define the coordinates of space tracks with accuracy up to the width of the chamber. As a result, the calorimeter has 4 levels of observation: (1 + 2 row) are at the - 1st level; (3 + 4 row) are at the 2nd level; (5 + 6 row) are at the 3rd level; (7 + 8 row) are at the 4th level (see **Figure 2**).

3. Registration and Analysis of “Hadron-M” Experimental Data

The database of the “Hadron-M” complex installation is available at www.tien-shan.org (accessed on 15 December 2022), which can be accessed via the local network by remote client programs with specific requests for data processing [9][10].

The experimental data bank of the “Hadron-M” complex installation has a two-level structure. The initial bank Bank-0 contains physical and test events of operational control of the installation. The test event recording mode is designed to analyze the operation of individual channels of the recording system. The secondary bank Bank-1 contains events recorded in the physical mode Bank-0, taking into account the calibration characteristics for each individual channel.

Currently, the “Hadron-M” complex installation is conducting and planning the below studies:

- a study of anomalous absorption of hadrons along the depth of the operating installation [11][12][13];
- a study of correlations between the primary energy E_0 (determining EAS parameters from the energies of hadrons, neutrons, and electron-photon components) [14][15][16];
- a search for exotic particles and events (such as strangelets and Centauro events, characterized by an anomalous ratio of charged and neutral hadrons) [17][18][19][20][21].

As a result of many years of research at the present stage of science development, the general form of the energy spectrum of galactic cosmic rays has become known, the magnitude of which is of at least the 10th order. Throughout this range, the spectrum has a universal power-law form, and its exponent γ changes sharply at several characteristic points. The origin of these features in the primary spectrum of cosmic rays remains unclear to date, even though more than half a century has passed since the discovery of the most famous of them, namely, a sharp break in the value of the exponent of the power spectrum at $E_0 \sim 3{\cdot}10^{15}$ eV [22]. In some articles, this break is associated with the contribution of the so-called strangelets (particles of strange matter) [18][19][20].

A more thorough study of the processes in the narrow front cone of EAS is one of the most important problems in the physics of cosmic rays. Earlier studies of EAS cores at the Tien Shan and Pamir-Chacaltaya [23] stations showed new results [24]. In the context of the problem, two phenomena should be noted. First is the phenomenon of the coplanar emission of particles observed as events with the geometric alignment of most energetic subscores in the EAS’s central core [23][25][26]. Besides, events with an anomalous ratio of charged and neutral components have been observed, namely, the so-called “Centauro” events. To search for and study possible events of the “Centauro” type, the CMS-CASTOR detector (Centauro And Strange Object Research) very-forward calorimeter experiment [27][28] was designed and implemented as part of the CMS experiment at the LHC.

At present, the very-forward physics is being studied at the LHC by the LHCf (Large Hadron Collider forward) experiment [29]. LHCf is made up of two detectors which sit along the LHC beamline, at 140 metres either side of the ATLAS collision point. The location allows the observation of particles at nearly zero degrees to the proton beam direction ($8.81 < \eta < 9.22$ and $\eta > 10.76$). Each of the two detectors weighs only 40 kg and measures 30 cm long by 80 cm high and 10 cm wide. They can only detect neutral particles (neutrons, γ-rays etc.). Unfortunately, the dimensions of these detectors are too small to study correlations of most energetic particles.

One can formally say that the forward physics kinematic region is also studied by the FASER experiment [30]. However, FASER is searching for new light, long-lived and mostly weak-interacting particles that are produced at or close to the ATLAS interaction point, move along the beam collision axis line of sight, and then decay within the volume of FASER into visible decay products. Thus, the goals of the FASER experiment are not focused on the study of most energetic hadrons, which is what is considered in this research. A certain contribution to these studies could be made by the “Hadron-M” installation, which is aimed at studying the EAS central core [31].

Research carried out at the “Hadron-M” installation is aimed at studying the most energetic particles to solve the fundamental problems of cosmic ray physics related to the nature and propagation of primary cosmic rays from their sources to the Earth. Considering that the “Hadron-M” installation has no analog in the world, it can qualitatively show new results in the problem of identifying the “true” properties penetrating the cosmic ray components due to the complex and diverse structure of the installed detectors and the depth of the ionization calorimeter.

One of the tasks being solved at the “Hadron-M” installation relates to a study from the field of gamma-ray astronomy to calculate the trajectory from the observed EAS characteristics to the primary energy [11].

The gamma radiation detection method is based on the fact that the gamma block absorbs the electron-photon component (EPC) of cosmic rays, and the hadronic component, due to the small thickness of the gamma block, passes without interactions through the gamma block. Further interactions and generation of particles develop in the hadron block.

Taking into account that the “Hadron-M” installation is located on uneven mountainous terrain, the new calculations in the standard method were introduced to find the coordinates of primary particles. To determine the coordinates of the primary particle, the installation data on the thickness of the atmosphere passed by the shower were used, such as: the zenith angle of arrival of the shower θ, the azimuth angle φ of the shower, the total number of particles in the shower N_e at the observation level and their lateral distribution. The number of detectors available on the installation allows for the reduction of errors when finding angles. Knowledge of θ, φ, EAS arrival time (UTC), and the geographical co-ordinates of the installation allows one to unambiguously determine the point of the celestial sphere from which the primary particle came.

One of the topical tasks solved at the “Hadron-M” installation is the study of the interactions of hadrons with the nuclei of air atoms and the identification of their properties during the generation of secondary particles in the energy range $E > 10^{15}$ eV.

To study the composition of primary cosmic radiation and the passage of EAS, as well as to confirm previously obtained results, it is necessary to collect statistical material, conduct and play several different cascades from hadrons and muons, taking into account the structure of the calorimeter and the method of registration of the “Hadron-M” installation; calculate the composition and spectra of hadrons and muons in the EAS core at the height of the Tien Shan high mountain station for different energies and charges of primary nuclei using various models, including the CORSIKA package; and carry out a comparative analysis with the experimental data of the “Hadron-M” installation.

4. Conclusions

The new data obtained on the nature of the absorption of the hadronic component will provide an opportunity to obtain an answer to explain the anomalous absorption of cascades in EAS cores and, to some extent, establish the nature of the penetrating component of cosmic radiation.

The study of the penetrating component and coplanarity of EAS subcores is of fundamental importance, since it provides information both on the very-forward physics of strong interactions and on the PCR composition. Confirmation of the phenomenon of strong coplanarity of EAS subcores may indicate both insufficient understanding of the hadron-generation mechanisms in the forward cone [32] and problems in understanding of the cosmological characteristics of the dimension of our space [33][34][35].

Results of the Tien Shan high-mountain experiments to study EAS characteristics may indicate the appearance of an additional PCR component and support the hypothesis of the presence of particles of strange quark matter in the PCR [18][19] at energies above 10^{16} eV. Confirmation of this hypothesis may become an important discovery both in the field of astrophysics and in elementary particle physics, since the presence of such particles is impossible without the existence of stars consisting of stable strange quark matter with a lifetime exceeding the lifetime of the Universe [18].

References

1. Nesterova, N.M.; Chubenko, A.P.; Djatlov, P.A.; Vildanova, L.I. The primary cosmic ray spectrum at 2·1013–2·1018 eV and its peculiarity above 1018 eV according to Tien Shan data. In Proceedings of the 24th International Cosmic Ray Conf., Roma, Italy, 28 August–8 September 1995; Volume 2, pp. 157–159.
2. Takibaev, Z.S.; Baigubekov, A.S.; Sadykov, T.K. Accelerated search for families of gamma quanta in an X-ray emulsion chamber. PTE 1977, 3, 70–71.
3. Babaev, M.K.; Baigubekov, A.S.; Sadykov, T.K. Analysis of nuclear-electronic cascades formed by hadrons of cosmic rays in the energy region E3≥1013 eV. NEWS Natl. Acad. Sci. Repub. Kazakhstan 2001, 6, 53–56. (In Russian)
4. Eremenko, Y.A.; Kalinin, Y.G.; Martyanov, I.S.; Sadykov, T.K.; Zastrozhnova, N.N. Multi-channel analog processor with 5·105 dynamic range for registration of interaction at super-high energies in the cosmic rays. Nuclear Instr. Meth. Phys. Res. A 2001, 459, 273–277.
5. Alibekov, M.E.; Babaev, M.K.; Baigubekov, A.S.; Sadykov, T.K. Simulation of the processes of passage of various particles through the atmosphere and the experimental setup “Hadron-44”. In Nuclear Interactions of Particles of High and Ultrahigh Energies; Science: Alma-Ata, Kazakhstan, 1989; pp. 21–30. (In Russian)
6. Kalinin, Y.G.; Martyanov, I.S.; Sadykov, T.K.; Zastrognova, N.N. The simple method to adapt time sampling of the analog signal. Nucl. Instr. Meth. Phys. Res. A 2004, 524, 374–376.

7. Sadykov, T.K.; Dalkarov, O.D.; Ryabov, V.A. Hadron-55 complex setup for study of hadron interactions within the central part of EAS. In Proceedings of the 34th International Cosmic Ray Conference, Hague, The Netherlands, 30 July–6 August 2015; Available online: http://pos.sissa.it/archive/conferences/236/570/ICRC2015_570.pdf (accessed on 3 February 2023).
8. Idrissova, T.; Sadykov, T.; Burtebayev, N.; Ryabov, V.; Zhukov, V. Complex installation Hadron-55 for registration of wide atmospheric showers. Acta Phys. Pol. B (Proc. Suppl.) 2021, 14, 681–686.
9. Sadykov, T.K.; Argynova, A.K.; Jukov, V.V.; Novolodskaia, O.A.; Piskal', V.V. Modernization of the peripheral detectors of Tien-Shan ionization-neutron calorimeter detectors "Hadron-55". News Natl. Acad. Sci. Repub. Kazakhstan 2021, 4, 121–128. (In Russian)
10. Mukashev, K.; Argynova, A.; Zhukov, V.; Idrissova, T.; Iskakov, B.; Piskal, V.; Sadykov, T.; Sadykov, Z.; Stepanov, A.; Serikkanov, A. The Complex of Experimental Facilities for the Cosmic Ray Investigation at the Tien Shan Mountain Station. Appl. Sci. 2022, 12, 465.
11. Mukashev, K.M.; Sadykov, T.K. Physics, Astrophysics of Cosmic rays and Anomalous Effects in Hadron Interactions; Almatykitap: Almaty, Kazakhstan, 2011; p. 375. ISBN 978-601-232-538-6. (In Russian)
12. Chubenko, A.P.; Shepetov, A.L.; Antonova, V.P. The modern status of anomalous delayed particles effect in the "Knee" region EAS according to the data of Tien Shan mountain station. In Proceedings of the 28th International Cosmic Ray Conference, Tsukuba, Japan, 31 July–7 August 2003; pp. 69–72.
13. Baigubekov, A.S.; Beisembaev, R.Y.; Sadykov, T.K. Anomalously delayed particles in extensive air shower core according to result of the new plant. In Proceedings of the 28th International Cosmic Ray Conference, Tsukuba, Japan, 31 July–7 August 2003; Volume 6, pp. 61–64.
14. Mukhamedshin, R.A. On alignment of most energetic substructures of γ-ray-hadron families and hadron interactions at E0 > 1016 eV. In Proceedings of the 29th International Cosmic Ray Conference, Pune, India, 3–10 August 2005; Volume 5, p. 448.
15. Argynova, A.K.; Iskakov, B.; Jukov, V.V.; Mukashev, K.M.; Muradov, A.D.; Piskal, V.V.; Saduyev, N.O.; Sadykov, T.X.; Salihov, N.M.; Serikkanov, A.S.; et al. The perspective fundamental cosmic rays physics and astrophysics investigations in the Tien-Shan high-mountain scientific station. News Natl. Acad. Sci. Repub. Kazakhstan 2019, 6, 121–138.
16. Mukashev, K.M.; Argynova, A.K.; Beisenova, A.D.; Iskakov, B.A.; Mukhamedshin, R.A.; Novolodskaya, O.A.; Piskal, V.V.; Ryabov, V.A.; Sadykov, T.K.; Serikkanov, A.S.; et al. Search for structures in the distribution of particles from the central area of wide atmospheric showers conducted on the Adron-55 installation. Phys. Sci. Technol. 2019, 6, 75–83.

17. Slavatinsky, S.A. Results of emulsion chamber experiments with very high-energy cosmic rays which are difficult to explain in the framework of the standard model. Nucl. Phys. B Proc. Suppl. 2003, 122, 3–11.
18. Witten, E. Cosmic separation of phases. Phys. Rev. D 1984, 30, 272–285.
19. Shaulov, S.B. Nuclear-Physics Model of the Knee in the EAS Spectrum. Phys. At. Nucl. 2018, 81, 638.
20. Bucciantini, N.; Drago, A.; Pagliara, G.; Traversi, S.; Bauswein, A. Formation and evaporation of strangelets during the merger of two compact stars. Phys. Rev. D 2022, 106, 103032.
21. Gladysz-Dziadus, E. Are Centauros exotic signals of the quark-gluon plasma? Phys. Part. Nucl. 2003, 34, 285–347.
22. Kulikov, G.V.; Khristiansen, G.B. On the size spectrum of extensive air showers. Sov. Phys. JETP 1959, 35, 441–444.
23. The Pamir Collaboration. Search for events with coplanar divergence of super high energy particles. In Proceedings of the 4th International Symposium on Very High Energy Cosmic Ray Interactions, Beijing, China, 29 October–3 November 1986; pp. 429–437.
24. Iskakov, B.A.; Argynova, A.K.; Beisenova, A.D.; Zhautykov, B.O.; Idrisova, T.K.; Novolodskaya, O.A.; Piscal, V.V.; Ryabov, V.A.; Sadykov, T.K.; Sadykov, J.T.; et al. “HADRON-55” complex setup for study of hadron interactions within the central part of cosmic ray extensive air showers (EAS) cores. J. Instrum. 2020, 15, 12002.
25. Rakobolskaya, I.V.; Roganova, T.M.; Sveshnikova, L.G. Energy dependence of charm production cross section at high energies. Nucl. Phys. B (Proc. Suppl.) 2003, 122, 353–356.
26. Sveshnikova, L.G.; Chubenko, A.P.; Mukhamedshin, R.A.; Popova, N.S.; Nikolskaya, N.M.; Yakovlev, V.I. On abnormal absorption of hadron component of EAS cores in lead and possible explanations. arXiv 2007, arXiv:0701219.
27. The CMS Collaboration. The very forward CASTOR calorimeter of the CMS experiment. J. Instrument. 2021, 16, P02010.
28. The CMS Collaboration; TOTEM Collaboration. Measurement of pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s}$ = 8 TeV by the CMS and TOTEM experiments. Eur. Phys. J. C 2014, 74, 2053.
29. The LHCf Collaboration. The results from LHCf and future prospects. EPJ Web Conf. 2013, 52, 01007.
30. The FASER Experiment. Available online: https://faser.web.cern.ch/physics (accessed on 6 February 2023).

31. Shaulov, S.B.; Beyl, P.F.; Beysembaev, R.U.; Beysembaeva, E.A.; Bezshapov, S.P.; Borisov, A.S.; Cherdyntceva, K.V.; Chernyavsky, M.M.; Chubenko, A.P.; Dalkarov, O.D.; et al. Investigation of EAS cores. EPJ Web Conf. 2017, 145, 17001.
32. Mukhamedshin, R.A. On connection between the collider long-range near-side “ridge” effect at $|\eta| < 2.4$ and cosmic-ray coplanarity of most energetic particles. Eur. Phys. J. C 2022, 82, 155.
33. Anchordoqui, L.A.; Dai, D.C.; Goldberg, H.; Landsberg, G.; Shaughnessy, G.; Stojkovic, D.; Weiler, T.J. Searching for the Layered Structure of Space at the LHC. Phys. Rev. D 2011, 83, 114046.
34. Anchordoqui, L.A.; Dai, D.C.; Fairbairn, M.; Landsberg, G.; Stojkovic, D. Vanishing Dimensions and Planar Events at the LHC. Mod. Phys. Lett. A 2012, 27, 1250021.
35. Stojkovic, D. Vanishing Dimensions: A Review. Mode. Phys. Lett. A 2013, 28, 1330034.