THE HERO (HIGH-ENERGY RAY OBSERVATORY) SIMULATION

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Abstract

The main aims of the High-Energy Ray Observatory (HERO) mission are direct measurements of very high energy cosmic ray. Measurements will concern the following scientific goals: detailed study of cosmic rays energy spectra in knee region, search for signatures of dark matter particles. HERO is planned to be launched onboard a heavy satellite. This experiment is based on the application of a wide aperture (>2π) deep (~5λ) ionization calorimeter. The effective geometrical factor of the apparatus is not less than 8 m2sr depending on the type of particles. Under the long exposure (~10 years), this mission will make it possible to precisely measure cosmic rays up to 10^{17}eV. Monte-Carlo simulations were performed to obtain instrument response for cosmic ray protons and different nuclei, including helium, carbon and iron

1.Introduction

Several successful missions ATIC [1,2], CREAM [3,4], TRACER [5], AMS02 [6,7], SOKOL-2 [8,9], NUCLEON [10-12], have been carried out to investigate high energy cosmic rays (CR). The abundant CR nuclei spectra were measured up to $5{\bullet}10^{13}$ eV. Some space CR missions are being conducted simultaneously in Earth orbit now. However, the 10^{15}–10^{16} eV energy region (the "knee" region) remains out of reach for current and planned missions, although this energy region is important to investigate astrophysical processes. Therefore, a new "breakthrough" experiment is necessary to measure energy spectra and cherge composition in the "knee" area. The main requirement with regard to such a mission is a radical increase in the exposure factor.

2. **The general concept of the HERO experiment**

The main aim of the HERO mission is the direct measurement of cosmic rays in the 10^{15}–10^{16} eV energy region. At least 100 particles with energies $>10^{16}$ eV must be registered. Therefore, an effective exposure factor of not less than 100 m2sr year is necessary in accordance with the intensities measured by extensive air showers (EAS) experiments.

The HERO experiment can be performed by means of the ionisation calorimeter method. A tungsten-scintillator calorimeter can be used for energy measurement. The detailed parameters of the device can be determined by the scientific goal and the technical possibilities.

The Russian space science vehicle is planned to operate in orbit for more than 7 years. It is possible to formulate the basic requirements for the HERO apparatus: its effective geometrical factor has to be at least 7-10 m2sr. The current and previous CR mission goals are to investigate CR up to the highest possible energies. Due to the limited resources of a space experiment, it was impossible to combine an increased exposure factor with high energy resolution. The other main HERO requirement is adequate energy resolution. The third HERO requirement is CR charge resolution in all energy and charge ranges, including rare secondary CR nuclei. An additional research task is the selection of electromagnetic (electron and gamma-ray) CR components.

The maximum payload for the planned satellite at a low (~ 500 km) orbit is 17 tons, yet no more than 12.5 tons of the overall vehicle mass can be made up of scientific equipment. The calorimeter weight must not exceed 10 tons. According to preliminary evaluations, the thickness of the calorimeter should be almost 3 inelastic interaction lengths or 52 radiation lengths

A layered 3D construction is proposed for the IC. Layers are composed of a combination of heavy (tungsten) and light (polystyrene) substances.

Thus we applied next values of the device parameters for the Monte-Carlo simulation.

The total weight of the tungsten-polystyrene calorimeter is equal to 10 tons. This calorimeter is hexagonal prism-shaped. The circumscribed diameter is equal to 1600 mm, the height of the prism is equal to 1500 mm. The calorimeter consists of 52 tungsten-scintillator layers. The charge detector consists of four silicon layers surrounded the calorimeter (fig.1).

The energy resolution was defined as a relative deviation of reconstructed and true values of energy using a Monte-Carlo simulation for various event selection criteria.

3. Simulation of the experiment

The program GEANT4.10.3 was applied to simulate the HERO experiment. The simulated trajectory distibution was isotropic. We simulated fluxes of protons and He, C, Fe nuclei for fixed energies 0.1, 1, 10, 100 TeV and for a uniform distributon of the logarithmic energy.

The aims of the simulation included elaboration of energy reconstruction algorithms and evaluation of the back scattered particles flux in the charge measurement system.

We applied the simple trigger criteria to select events with more than 5 high energy deposit layers. The same trigger was applied in the SOKOL experiment [8,9].

The simulated databanks were proceeded to solve above-mentioned problems. The main problem of the charge measurement is to separate protons and helium nuclei at the high energies. Back scattered particles caused additional ionization in the charge detectors. The charge silicon detectors must be divided into pads of 1 cm2 square. We plan to subtract mean value of the back scattered particles signal from the axis pad sinal. The mean value of the back scattered particles signal is equal to the mean signal in neighbouring pads.

We applied the rank statistics [10] too. The charge distribution obtained for 100 TeV protons and helium nuclei is presented in fig.2. These types of particles are reliably separated.

We applied the simple method of energy reconstruction based only on registration of the total energy deposit for events selected by trigger criteria. Some examples of reconstructed energy distribution are presented in fig.3 for disrete values of the primary energy. Values of energy resolution are presented in Table 1.

The simulated and reconstructed energy spectra are presented in fig.4.

4. Conclusion

The effective exposure factor of HERO and its measuring accuracy will provide the ability to solve several main problems found in astroparticle physics in the foreseeable future. These include the "CR knee" problem, a phenomenon that even 60 years after its discovery still remains uninterpreted.

REFERENCES

1. H.S. Ahn et al. Advances in Space Research 37, 1950 (2006)
2. A.D. Panov et al. Advances in Space Research 37, 1944 (2006)
3. H.S. Ahn et al. The Astrophysical Journal, 707, 593 (2009)
4. Y.S.Yoon et al. The Astrophysical Journal, 728, 122 (2011)
5. A. Obermeier et al. The Astrophysical Journal, 742,14 (2011)
6. M. Aguilar et al. Phys. Rev. Lett. 115, 211101 (2015)
7. M. Aguilar et al. Phys. Rev. Lett. 114, 171103 (2015)
8. I. P. Ivanenko et al. Proc. 23 ICRC 2, 17-19. Calgary. Canada.(1993)
9. A.Turundaevskiy and D. Podorozhnyi. Advances in Space Research 60, 1578 (2017)
10. E. Atkin et al. Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 770, 189 (2015)
11. E. Atkin et al. Astroparticle Physics 90, 64 (2017)
12. E. Atkin et al. Journal of Cosmology and Astroparticle Physics. 2017(7):20.

Table 1. Energy resolution,%

E eV	protons	He	C	Fe
10^{11}	18	41	29	12
10^{12}	31	47	39	39
10^{13}	29	49	49	39
10^{14}	23	47	47	47

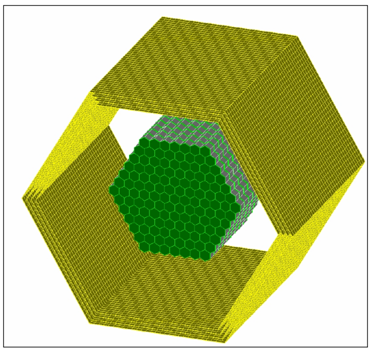

Fig.1. The general structure of the HERO device applied by the simulation

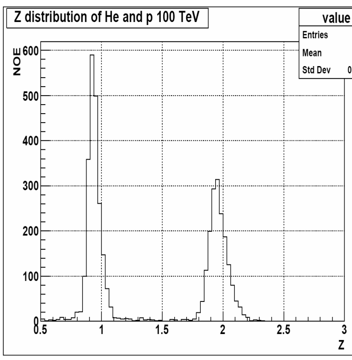

Fig.2. The simulated charge distribution for high energy protons and helium nuclei

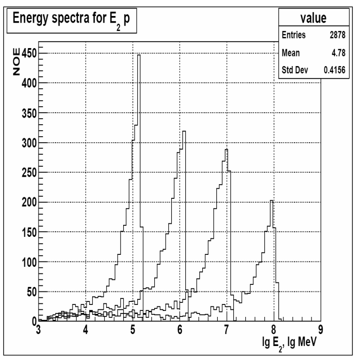

Fig.3. Reconstructed protons energy distributions for discrete values of the primary energy

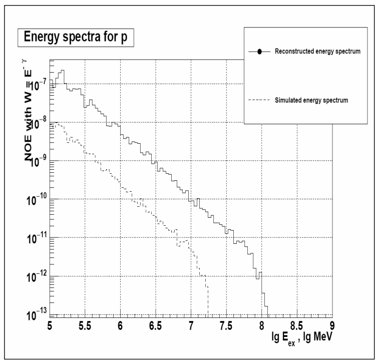

Fig.4. Simulated and reconstructed energy spectra of protons