COMPARISON OF GHEISHA QGSJET AND UrQMD EPOS INTERACTION MODELS TO COMPARE EXPERIMENTS WITH OBSERVATION PARAMETERS OF TSHSS*

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Received 17 November 2022, accepted 17 November 2022, published online 26 January 2023

To study Extensive Air Showers (EAS) at the Tien-Shan High Mountain Science Station (TSHMSS), a layout of an 8-channel Burst Detector (BD) was created. On the basis of the BD layout, a 24-channel BD prototype section is being developed to obtain preliminary experimental data. To evaluate the operation of the future prototype of the BD, the development of EAS was simulated at various interaction energies of the primary particle with the Earth's atmosphere using the CORSIKA simulation package. Two combinations of interaction models for high-energy and low-energy interactions GHEISHA+QGSJET and UrQMD + EPOS have been chosen in this work. The simulation was carried out taking into account the height above the sea level parameter, the geomagnetic cutoff at a given geographical point (the parameters of the Earth's magnetic field) of the prototype of the BD section with different types of primary particles, in a pre-selected energy range. After processing the output data using Python scripts, the type of particle, its energy, momentum, and coordinates at the observation level have been obtained, which are analyzed and optimized to compare the various received models.

DOI:10.5506/APhysPolBSupp.16.2-A5

1. Introduction

The history of cosmic rays (CR) studies in the primary energy range of 10^{14}–10^{17} eV has at least half a century, but despite this, many unresolved is-

* Presented at the IV International Scientific Forum *Nuclear Science and Technologies*, Almaty, Kazakhstan, 26–30 September, 2022.

sues remain in their properties [1]. In the same range of E_0 values, a number of other interesting effects were discovered that have not received a generally accepted explanation, for example, difficulties in reconciling the results of various experiments to determine the mass composition of primary CR [2] and the excess of muon multiplicity values that are recorded in EAS with $E_0 \geq 10^{16}$ eV, estimates based on modern models of hadron interaction [3].

At present, studies of hadronic interactions at accelerators and in experiments with CR turn out to be complementary to each other.

The Tien Shan complex of detectors provides simultaneous registration of the electron–photon, hadron, and muon components of EAS, detectors of Cherenkov and radio radiation from shower particles, and detectors of neutrons and low-energy gamma rays associated with the passage of EAS [4, 5].

One of the common ways is the registration of the EAS electromagnetic component. One of the disadvantages of this method is low sensitivity of the electromagnetic component to nuclear processes and the need to use nuclear cascade models when interpreting EAS data. Another research method involves the study of EAS cores, where the most energetic hadrons of the cascade are concentrated, carrying the main information about the primary CR nuclei. The characteristics of the hadronic component of EAS cores will make it possible to obtain direct data on the composition of primary cosmic radiation in the "knee" region.

To study EAS at the TSHMSS an 8-channel layout of BD was created [6]. On the basis of the BD layout, a 24-channel BD prototype section is being developed to obtain preliminary experimental data. To evaluate the operation of the future prototype of the BD, the development of EAS was simulated at various interaction energies of the primary particle with the Earth's atmosphere using the CORSIKA simulation package. Two combinations of interaction models for high-energy and low-energy interactions GHEISHA+QGSJET and UrQMD + EPOS have been chosen for this work.

2. High-energy and low-energy models of hadron interaction in CORSIKA

CORSIKA (COsmic Ray SImulations for KAscade) is a program for detailed simulation of extensive air showers initiated by high and ultrahigh energy CR particles. Protons, light nuclei up to iron, photons, and other elementary particles can be considered primary CR [7].

The CORSIKA simulation package contains various interaction models. Hadron interactions at high energies have several alternative interaction models: the VENUS [8], QGSJET [9–11], and DPMJET [12] models are based on the Gribov–Reggae theory [13–15], neXus is based on a simple combination of QGSJET and VENUS. The most recently added EPOS model is based on the neXus structure, but with very important improvements affecting the hard interactions of both the nuclear and high density effects. HDPM is inspired by the results of the Double Parton Model [16] and seeks to reproduce kinematic distributions measured at colliders.

For hadronic interactions at low energies, the GHEISHA [17], FLUKA [18, 19] interaction models or the UrQMD [20, 21] microscopic model are used.

In the decay of particles, all decay branches up to the 1% level are taken into account. For electromagnetic interactions, a specially developed version of the EGS4 program or NKG analytical formulas can be used [22].

QGSJET (Quark Gluon String model with JETs) is a model developed to describe high-energy hadronic interactions using the Pomeron quasi-eikonal parameterization for the amplitude of elastic hadron–nucleon scattering. The process of hadronic interactions is considered in the Quark Gluon String model. The latest version of QGSJET-II-04 [23] includes the Pomeron loop and the cross section is tuned to the LHC data.

3. Simulation results of the comparison of models

As part of the work performed, the GHEISHA+QGSJET and UrQMD+EPOS interaction models based on the CORSIKA 77410 versions were tested to compare.

Table 1 shows the time spent on simulation using each model for several energies of the primary particle.

Table 1. Duration of simulation of each hadron interaction.

Primary particle energy [GeV]	Simulation time [s]	
LEHIM HEHIM	GHEISHA QGSII	UrQMD EPOS
2×10^4	3570	4204
	2837	4860
	3695	4993
4×10^4	3673	4790
	3239	4783
	3198	4015
6×10^4	3195	5233
	2941	4738
	3328	3946

As can be seen from Figs. 1–4, the difference between the GHEISHA+ QGSJET and UrQMD + EPOS interaction models is insignificant, but the estimated simulation time for GHEISHA+QGSJET (Table 1) is about 25% faster. This is important due to the fact that with an increase in the primary energy of the particle, the simulation time increases significantly, so in what follows, we will use the GHEISHA+QGSJET interaction model.

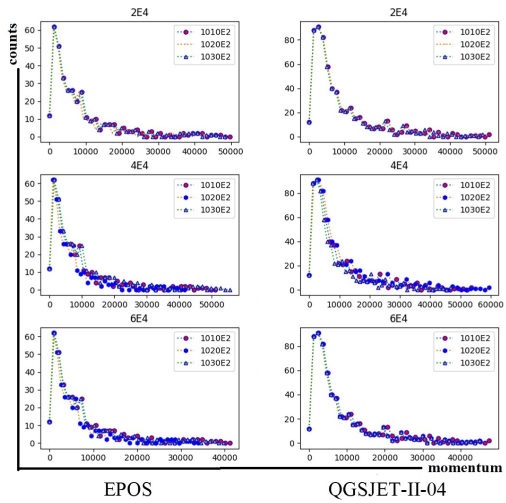

Fig. 1. Distribution of hadron momenta at the observation level of 1010, 1020, and 1030 m a.s.l. at the primary particle energies of 2, 4, and 6×10^4 GeV.

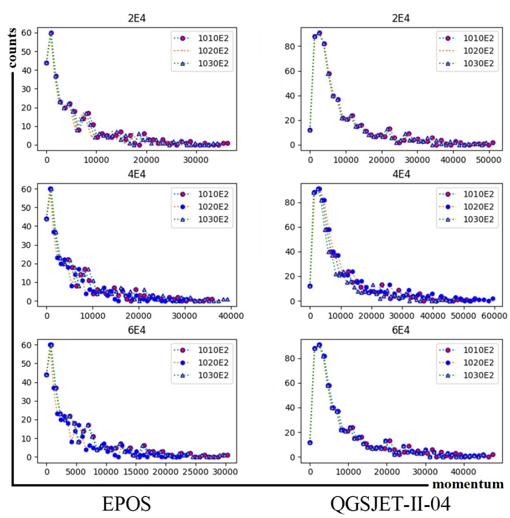

Fig. 2. Distribution of muons momenta at the observation level of 1010, 1020, and 1030 m a.s.l. at the primary particle energies of 2, 4, and 6×10^4 GeV.

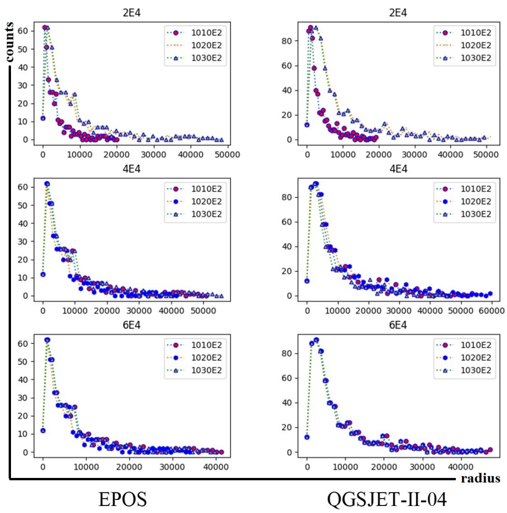

Fig. 3. Distribution of the deviation radius from the center of the EAS core for hadrons at the observation level of 1010, 1020, and 1030 m a.s.l. at the primary particle energies of 2, 4, and 6×10^4 GeV.

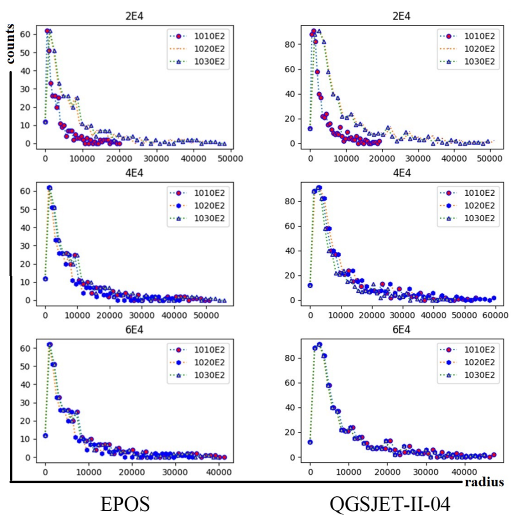

Fig. 4. Distribution of the deviation radius from the center of the EAS core for muons at the observation level of 1010, 1020, and 1030 m a.s.l. at the primary particle energies of 2, 4, and 6×10^4 GeV.

The simulation was carried out taking into account the altitude parameter, the geomagnetic cutoff at a given geographical point (the parameters of the Earth's magnetic field). Modeling was carried out for the terrain TSHMSS height 3340 meters above sea level. Magnetic field parameters were as follows: N 430 2' (43.047171 GV); E 760 56' (76.945348 GV). A proton with an energy of 10^{15} eV was chosen as the primary incident particle. In the simulation, azimuthal angles from 0 to 180 degrees were worked out.

After processing the output data using Python scripts, the type of particle, its energy, momentum, and coordinates at the observation level have been obtained, which have been analyzed and optimized to compare the various obtained models (Figs. 5–6).

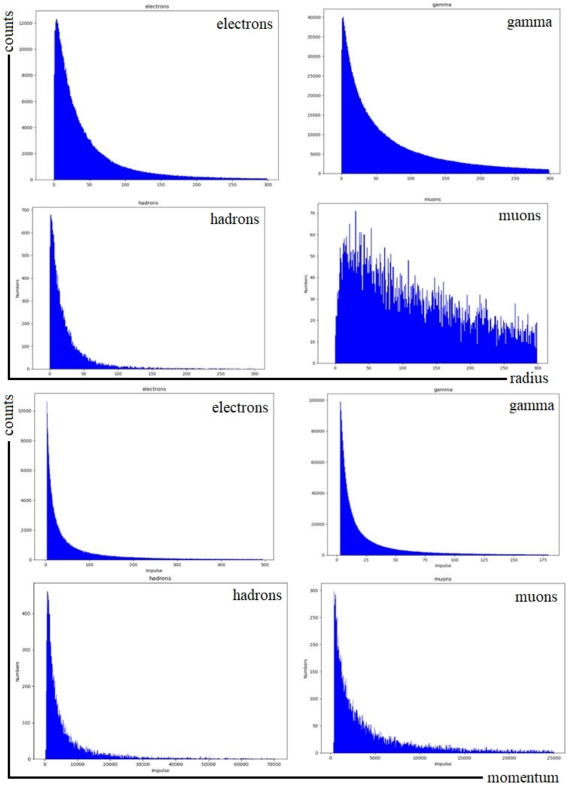

Fig. 5. Momentum distributions at an energy of the primary particle of 10^{15} eV at the azimuth and zenith angle of 0°.

The next simulation task using the GHEISHA+QGSJET interaction model will be the simulation of primary protons with energies of $10^{16}, 10^{17}$, 10^{18} eV at various azimuth and zenith angles. After the simulation is completed for all possible energies and for all angles of arrival of primary particles, the simulation results will be compared to the experimental data obtained using the 24-channel BD section.

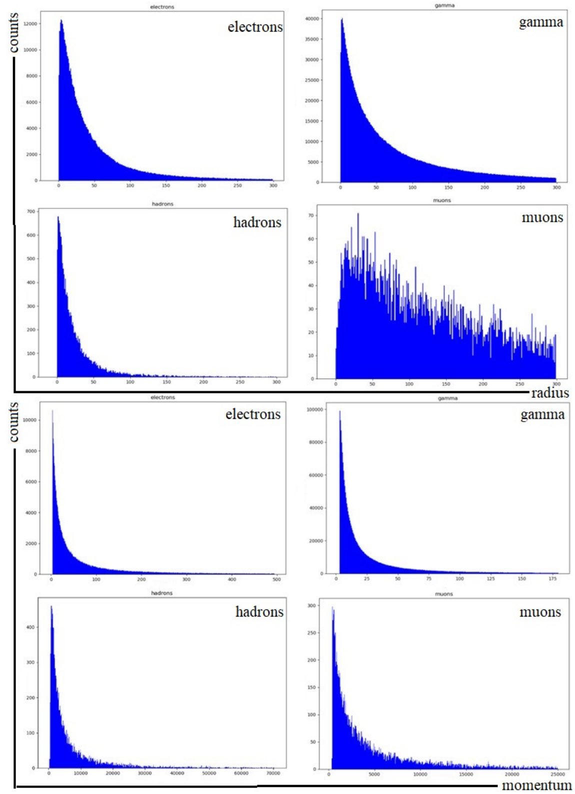

Fig. 6. The CORSIKA simulation results at primary particle energy 10^{15} eV at 90° azimuth and 0° zenith angle.

4. Conclusion

The GHEISHA+QGSJET and UrQMD + EPOS interaction models based on CORSIKA versions were evaluated and compared. Based on the evaluation and comparison results, it is optimal to use the GHEISHA+QGSJET interaction model for further calculations.

The CORSIKA simulation was carried out using the GHEISHA+QGSJET interaction model optimally chosen with azimuth angles of 0° and 90° and zenith angle of 0° at a primary proton energy of 10^{15} eV.

This research has been funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Program No. BR10965191 “Complex Research in Nuclear and Radiation Physics, High Energy Physics and Cosmology for the Development of Competitive Technologies”).

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