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Nuclear Mass Range of Primary Event From the Observation of Shower in Very High Energetic Cosmic Rays at Energy ~ 10^7GeV

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Abstract: *In the studies of very highly energetic cosmic ray interactions (VHECRI), the discovery of mass numbers relating to the primary nuclei firing up the atmospheric extensive air showers (EAS) is essential in understanding the nature of both VHECRI and EAS. The present study implements a simple analysis technique to determine the mass number of primary nucleus that starts the EAS cascade for processing the shower data coming from a detector height-level (~1400 m above sea level). CORSIKA 7.6900, which is the EAS-Monte Carlo generator, is used to produce detailed data on detector level and at primary energy* ~ 10^7 *GeV. Generated data for light and medium nuclear mass numbers are analyzed and the energy spectrum for the produced EAS is retrieved. The EAS light nuclei (H and He), medium nuclei (Mg) and heavy nuclei (Ti, Cr, Fe) spectra are obtained, totally and with a photon-content subtraction. It is found that, the spectral slope of the tail of the spectra with photons subtracted depend on the primary nuclei's mass number.*

Key Word: *primary event nuclei, CORSIKA, Very High Cosmic Rays Interactions (VHCRI), extensive air showers (EAS), spectral tail.*

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I. Introduction

Knowledge regarding the origin of the incident extraterrestrial nuclei and the nature of the interactions in atmospheric extensive air shower (EAS) at energies and momenta exceeds them in collider experiments is essential in predicting the cosmic nuclei sources. It is difficult to determine the energy spectra of primary nuclei of very highly energetic cosmic rays (VHECRI) since the occurrences of VHECRI are very uncommon. That is, as one occurrence per century, per one kilometer square of Earth's surface has a possibility of one VHECRI event. Several experiments, including wide area distribution arrays of detectors, collect energy spectra from the shower of secondary particles (e.g. Telescope array project [2], Pierre Auger detector in Argentina [1]). Shower energy spectra of EAS for one event carries information about the atomic mass, initial energy , and incidence angles of the primary nucleus. The measurement of mass composition of high energy cosmic rays above 10^{17} eV $= 0.1$ EeV can provide important indications about the origin of ultra high energy cosmic rays [3].

The energy spectrum of the cosmic ray collision events is a cascade-composition of a smooth power law spectrum $\mathrm{F(E) = const.\times E^{-\alpha}}$ of different values of the spectral index α. It has two characteristics that are recognizable. The first is the cosmic ray knee at about 3×10^6 GeV, where the spectrum steepens for the range of $\alpha = 2.7$ to 3.1, and the other one is the ankle, at about 3×10^9GeV, where the spectrum becomes again flatter [4]. Information about the origin, the acceleration mechanisms, and the nature of propagation in the galactic and intergalactic media are vital questions. Their answers are adequately found in the spectra of extraterrestrial nuclei. The recent state of knowledge is that, There is no idea about the cosmic ray sources at energies above the cosmic ray knee, except that the highest energy particles are certainly of extragalactic origin. It is understood that some astrophysical objects can accelerate particles to three orders of magnitude higher than the LHC equivalent lab energy [5].

The CORSIKA (COsmic Ray SImulations for KAscade) is a Monte Carlo EAS generator program for the physics of VHECRI, used by many cosmic ray experiments for various actions. It can be used to simulate interactions and decays of nuclei, hadrons, muons, electrons, and photons in the atmosphere up to energies of primary event equals to 10^{17}eV. It gives details for all secondary particles that are created in an air shower and travel under a selected observation level [6]. In the present wok, The shower simulations are performed using CORSIKA 7.6900 code [6] with hadronic interactions are modeled using the GHEISHA code [7] at low energies (E < 80 GeV). Moreover, the QGSJET [6, 8, 9]) are utilized as high energy interactions quark gluon jet generator. The EAS spectra due to CORSIKA 7.6900 is calibrated to the most recent state of the art on Pierre Auger observatory [5]. The power law distributions are considered in the code as the descriptive distribution of the total spectra of EAS. The surface detector in Pierre Auger Observatory (starting at 1 JAN 2014) could detect and identify charged particles and photons, as particle components of EAS, through 1660 water Cherenkov stations covering area of about 3000 km [5]. Hadrons constitute the most little abundant particle group in air showers. They contribute about %1 to the total shower particle flux but are exclusively responsible for the energy transport and supply in the shower process. Their existence are sensitive to hadronic interaction models which have to extrapolate to kinematical and energy regions not covered by present-day collider experiments. Therefore, they can be used to check the reliability of the interaction models [10].

The electromagnetic and muonic components of EAS are sensitive to the atomic mass of the primary cosmic particle. The relative contributions sizes of the components can be measured with detectors settled on ground, and the electromagnetic component in addition are detected indirectly via its radio emission in the atmosphere[11].

A straightforward method for estimating the mass number of the primary nucleus arriving from extraterrestrial sources is presented in the study. Six nuclei are in the focus of the research; Light nuclei (${}^{1}_{1}\mathrm{H}$ and ${}^{4}_{2}\mathrm{He}$), medium nuclei (${}^{24}_{12}\mathrm{Mg}$), and heavy nuclei (${}^{48}_{22}\mathrm{Ti}$, ${}^{52}_{24}\mathrm{Cr}$, ${}^{56}_{26}\mathrm{Fe}$), and are selected as primary extraterrestrial nuclei, where their spectra are compared. It is clearly found that, the spectra of the whole shower at the detector surface have similar behavior, but after the spectral photon-content subtraction, the spectral behavior depends on the mass number of the primary nucleus.

The paper is structured as follows; section I, after the introduction, provides a short summary of the proposed method. Results and discussion are presented in Section II. Eventually the conclusions is issued.

II. The method

The method is depending on; a- total energy spectrum is obtained for whole particles included in the EAS for each primary event. b- Pinpointing the photons (secondary photons and fluorescent photons). c- Eliminating photon-records from the spectrum and compare the whole spectrum with the no-photons spectrum. Several quantifying procedures are used to distinguish between spectral behaviors for different primary nuclei, but in this study, the whole and the no-photons spectra for each of studied six nuclei are presented, the quantified results are postponed to future articles. Table 1. shows the values of the parameters to begin the run of CORSIKA 7.6900

Table1. The input parameter to begin the simulation of EAS on CORSIKA 7.6900.

CORSIKA starting parameter names	value
Observation level (i. e. the height of the detector surface above see level.)	1400 m.
Starting height (level determined from the primary Collison center down to the earth surface.)	$0\ \mathrm{g/cm^2}$.
Primary particles	Light nuclei (H, He), medium nuclei (Mg), and Heavy nuclei (Ti, Cr, Fe)
Primary energy	10^{16} eV.
Shower sets	10 sets.
Shower/set	1000 records.
Zenith angle	0^{o}.
Azimuth angle	-180^{o} to 180^{o}.
Energy cut (hadrons, muons)	0.3 GeV.
Energy cut (electrons, photons)	0.003 GeV.
Earth's magnetic field (+ve x-axis is to the geographic north, and +ve z axis is to geographic east.)	$B_x = 25.005\ \mu T, B_z = 39.488\ \mu T$.

II. Result and discussion

The following figures 1,2,3 are arranged in ascending order of primary nuclei atomic-mass numbers in a manner leads to direct comparison between the whole spectra and the no-photons spectra. Figures 1 and 2 present the whole spectra in correspondence with the no-photons spectra for each of the primary nuclei. There is no difference between the profiles of whole spectra for different primary nuclei, except, may be, in the area under each spectrum. It is noted that, the tail of the no-photon spectrum becomes fatter and the area under the spectrum increases as the atomic number of the primary nucleus rise, irrespective of their start energy.

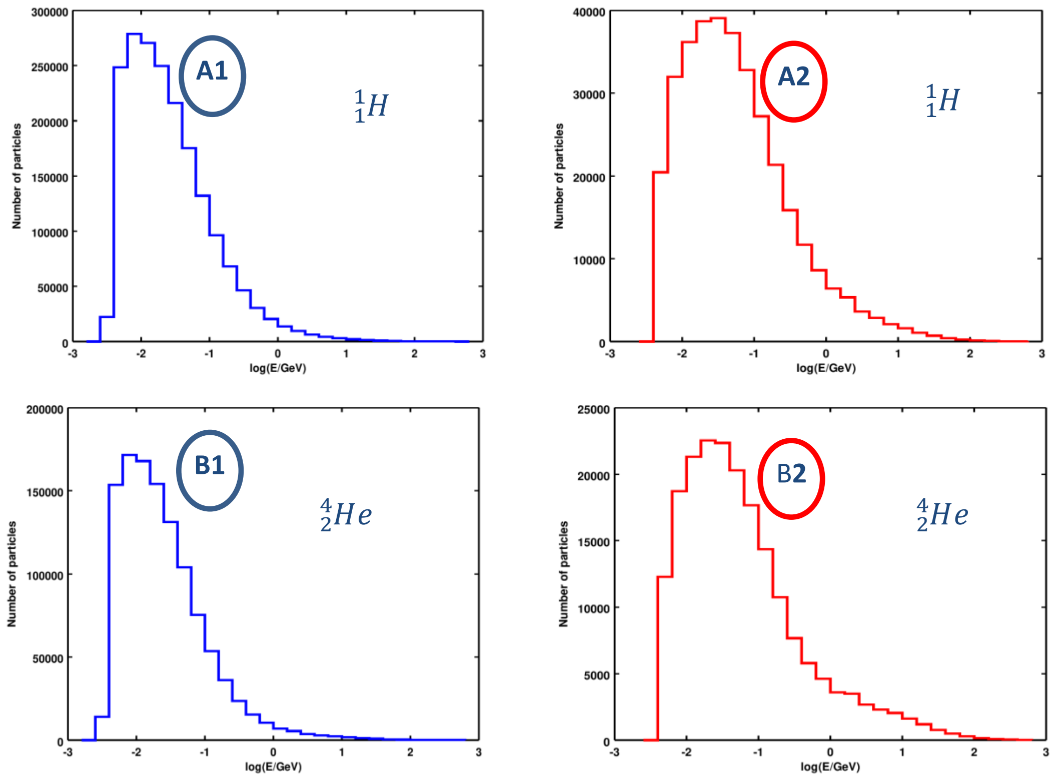

Figure 1. The spectra of log(E/GeV) of the EAS particles generated by CORSIKA 7.6900 for each of the light atomic mass extraterrestrial nuclei selected for this study. The left column are the whole spectra, and the right column are the no-photons spectra.

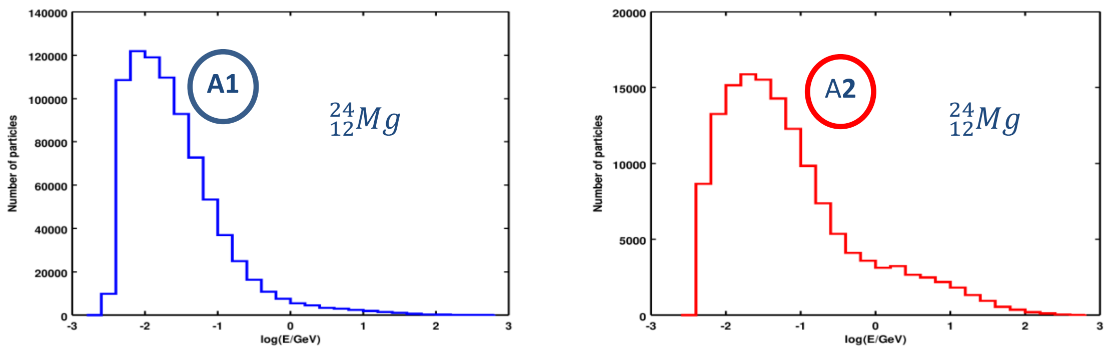

Figure 2. The spectra of log(E/GeV) of the EAS particles generated by CORSIKA 7.6900 for the medium atomic mass extraterrestrial nuclei selected for this study. The left column are the whole spectra, and the right column are the no-photons spectra.

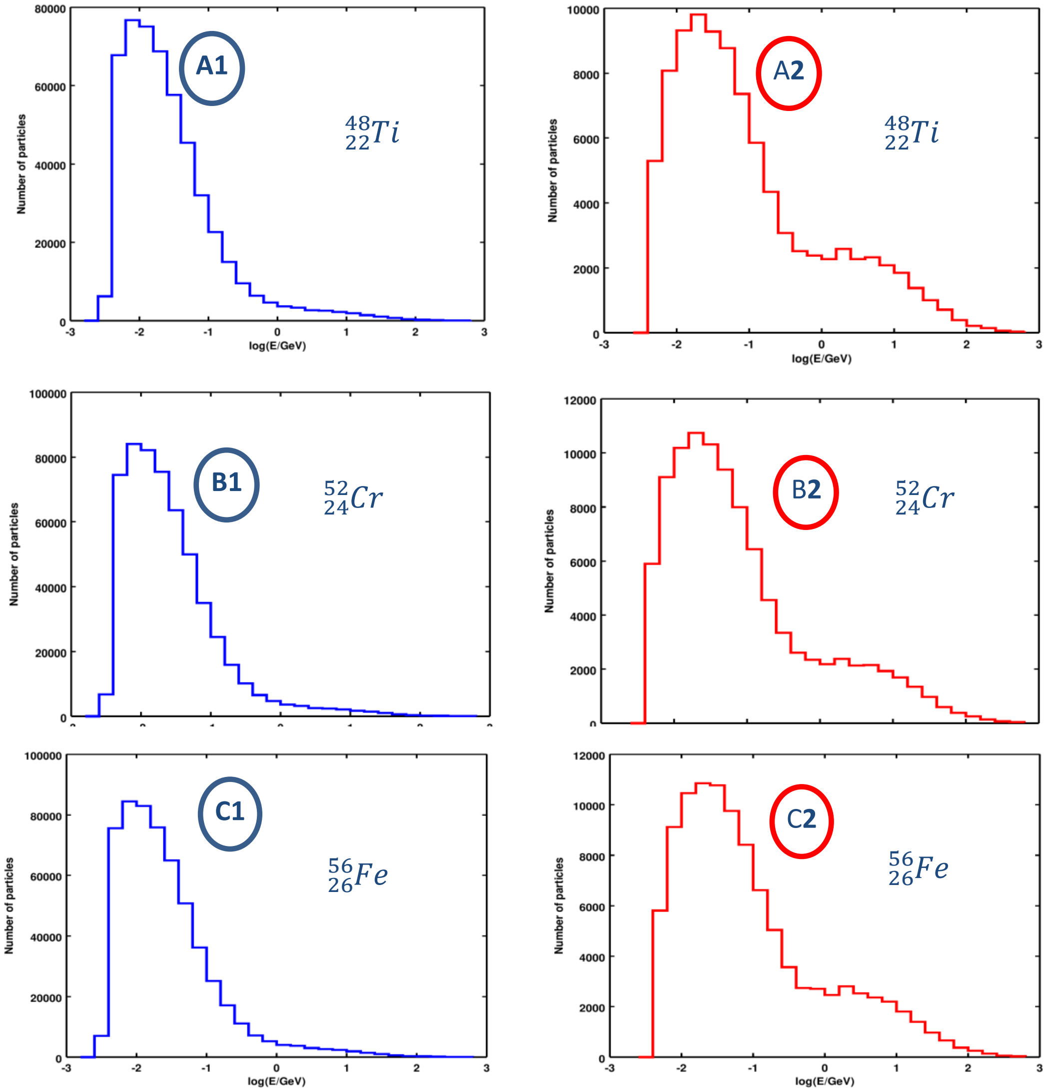

Figure 3. The spectra of log(E/GeV) of the EAS particles generated by CORSIKA 7.6400 for each of the heavy extraterrestrial nuclei selected for this study. The left column are the whole spectra, and the right column are the no-photons spectra.

Z. BAGHERI, et al. [12] provided standard calibration lines for high energy EAS which are useful in determination of the nature of fully contained electromagnetic showers, and demonstrate the shape function for the distribution of the photons around the mean shower axis. This reference found that, the photon distribution function about the shower axis is most probably a power law of the form,

$$F(r) = 1 - (1 + r/r_M)^{-2.5}, \tag{1}$$

Where r is the distance from the shower axis, r_M is the Moleire radius, which is a natural shower-perpendicular scale that is caused by multiple fully electromagnetic scattering, and determines the lateral distribution of electrons and photons in shower, and since the electron's radiation length in the air depends on air temperature and pressure, Moliere radius varies along the shower. Moleire radius depends to the first order on the radiation length of the air and the energy of the primary electron ignites electromagnetic EAS.

III. Conclusions

The method of recognizing the primary extraterrestrial nuclei by eliminating shower-photons from the total spectra and the study the fatness of the tail of no-photons spectrum and the total area under the spectrum gives behavior clearly and directly proportional to the mass number of the primary nucleus. The conclusion is valid, at least, for incidence energy of 10^{16} eV .

The future work is concerned with developing the method in order to quantify its predictions.

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