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Identification of nuclear mass range of primary event from the observation of shower in ultra-high energetic cosmic rays at energy ~ 10^6 GeV

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Abstract – Identification of mass numbers concerning the nuclei ignite the atmospheric extensive air showers (EAS) is vital in the studies of Ultra High Energetic Cosmic Rays Interactions (UHECRI). The present study introduces a simple technique in processing of the shower data at the detector level (1400 m over sea-level) to identify the nucleus that starts the cascade of the EAS. CORSIKA 7.6900, which is the EAS-Monte Carlo generator is used to generate detailed data at detection level 1400 m over sea-level and energy ~ 10^6GeV. The data are analyzed and the energy spectrum is obtained for the generated EAS. The EAS spectra for light nuclei (H and He), medium nuclei (Mg), and Heavy nuclei (Ti, Cr, Fe) are obtained, totally and with photons are subtracted. It is found that, the spectral slope of the tail of the spectra with photons subtracted depend on the primary nuclei's mass-number.

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Keywords- Ultra High Cosmic Rays Interactions; UHCRI; Primary event nuclei; CORSIKA; Extensive air showers; EAS; Spectral tail.

1. INTRODUCTION

Atmospheric extensive air shower (EAS), due to the collision of extraterrestrial very high energetic nucleus with atmospheric nuclei, carries information about the nature of the incident nucleus and the nature of the interactions at energies and momenta exceed those of collider experiments. Determination of Energy spectra of primary particles in ultra-high energetic cosmic rays (UHECR) is difficult because UHECR events are very rare. That is, everyone kilometer squared of earth surface has a chance of UHECR event as one event per century. Energy spectra of shower of secondary particles are obtained by several experiments including large area distributed detectors (e.g. Pierre Auger detector in Argentina [1], Telescope array project [2]). Shower energy spectra of EAS for one event carries information about the atomic mass, incidence angles, and initial energy of the primary nuclei. 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 cascade-composition of a smooth power law spectrum $F(E) = const. \times E^{-\alpha}$ of different values of the spectral index α. It has two identifiable features. The first one is the cosmic ray knee at about $3 \times 10^6\ GeV$, where the spectrum steepens for the range of $\alpha = 2.7\ to\ 3.1$, and the other one is the ankle, at about $3 \times 10^9 GeV$, 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 important questions, and their answers are adequately included in the spectra of extraterrestrial nuclei. The recent state of knowledge is that, at energies above the cosmic ray knee there is no idea about the cosmic ray sources, except that the highest energy particles are certainly of extragalactic origin. It is realizable, 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 simulation program for the physics of cosmic rays, 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 past a selected observation level [6]. The shower simulations are performed using CORSIKA 7.6900 code [6] with hadronic interactions are modeled using the GHEISHA [7] code at low energies (E < 80 GeV). Moreover, the QGSJET [6,8, 9])

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are utilized as high energy interactions. The EAS spectra due to CORSIKA 7.6400 is calibrated to the most recent studies on The 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 (science 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 least 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. They are sensitive to hadronic interaction models which have to extrapolate into 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 present work introduces a simple and direct method to estimate the mass number of the primary nucleus coming from extraterrestrial sources. The study includes six nuclei ($^{1}_{1}H$ and $^{4}_{2}He$), medium nuclei ($^{24}_{12}Mg$), and Heavy nuclei ($^{48}_{22}Ti$, $^{52}_{24}Cr$, $^{56}_{26}Fe$) as primary extraterrestrial nuclei, where their spectra are compared. It clearly found that, the spectra of the whole shower at the detector surface have similar behavior, but after the photon subtraction, the spectral behavior depends on the mass number of the primary nucleus. The paper is organized as, next to the introduction, section on presents a brief description of the proposed method. Section 2 is the results and discussion, and finally the conclusions.

1.1. *The method:*

The proposed method depending on; a- obtaining the energy spectrum of whole particle components included in the EAS for each primary event. b- identifying the photons (fluorescent photons and other secondary photons). c- removing 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 paper, the whole and the no-photons spectra for each of studied six nuclei are presented, the quantified results are deferred to future publications. Table 1. introduces the values of the parameters to initiate the run of *CORSIKA 7.6900*.

Table1. The input parameter to initiate the simulation of EAS.

CORSIKA input parameter	Value
*	10 times.
Shower/set	1000 records.
Primary particle	Light nuclei (H,He), medium nuclei (Mg), and Heavy nuclei (Ti, Cr, Fe)
Primary energy	10^{15} eV .
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.)	$B_x = 25.005\ \mu T, B_z = 39.488\ \mu T$.
Starting height (level determined from the primary Collison center down to the earth surface.)	0 g/cm^2.
Observation level (i. e. the height of the detector surface above see level.)	1400 m.

2. RESULTS AND DISCUSSIONS:

The following figures are arranged in descending 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 increases, irrespective of their start energy.

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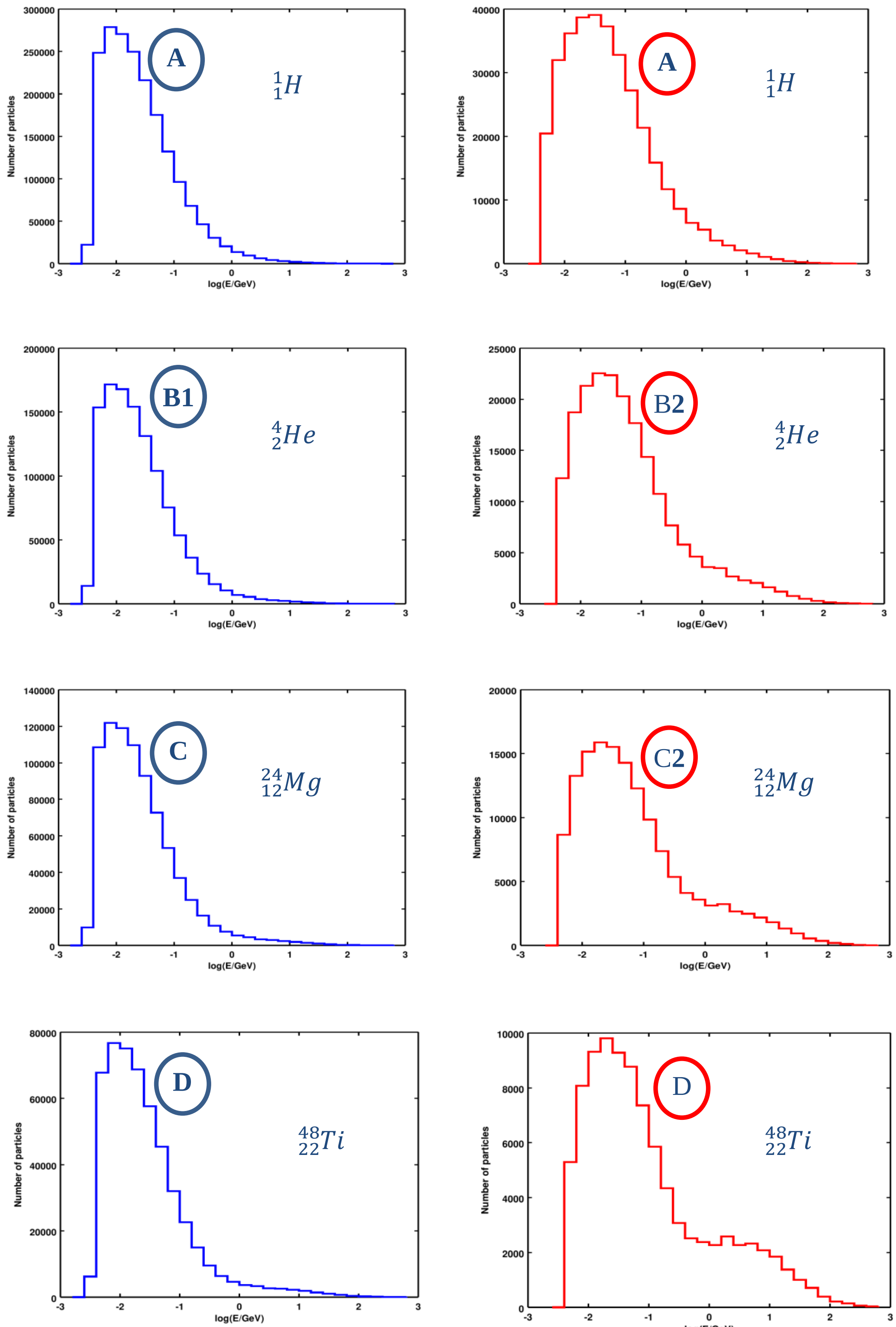

Fig. 1. The spectra of log(E/GeV) of the EAS particles generated by CORSIKA 7.6400 for each of the primary extraterrestrial nuclei selected for this study. The left column are the whole spectra, and the right column are the no-photons spectra.

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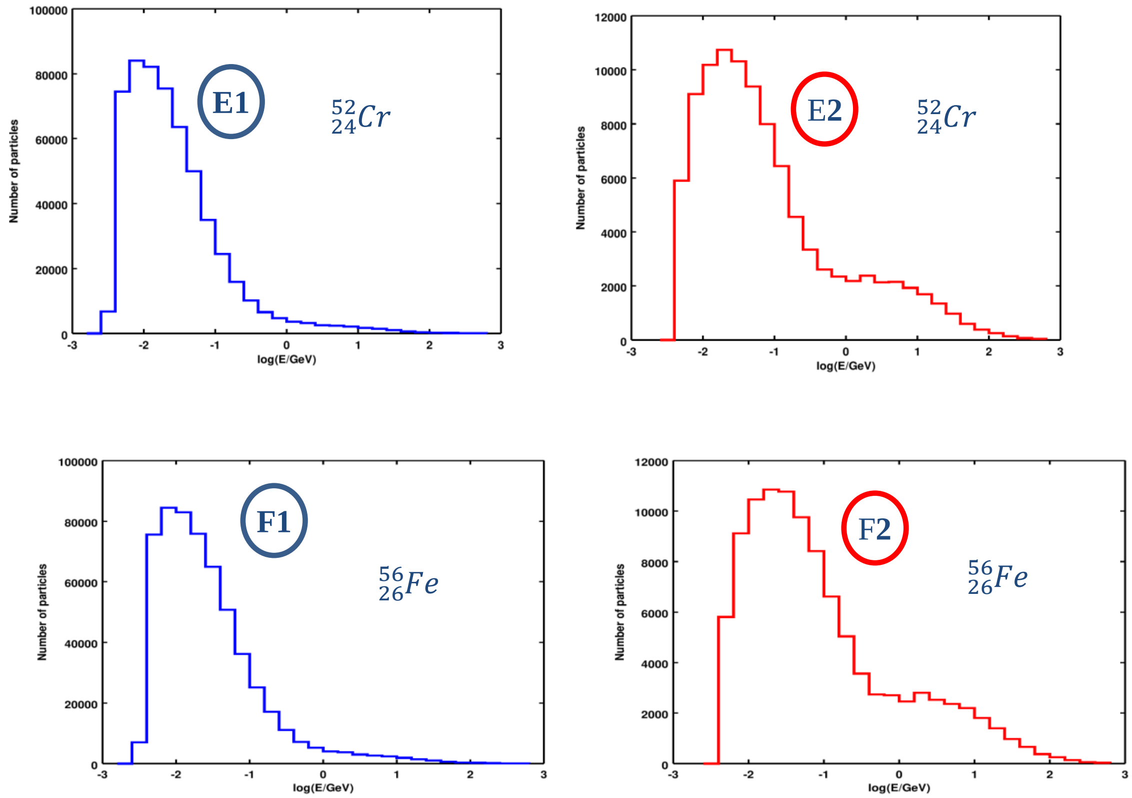

Fig. 2. The spectra of $\log(E/GeV)$ of the EAS particles generated by *CORSIKA 7.6400* for each of the primary extraterrestrial nuclei selected for this study. The left column are the whole spectra, and the right column are the no-photons spectra.

ZAHRA BAGHERI, et al. [11] had provided standard calibration lines for high energy showers which can be used to determine the nature of the particles, and demonstrate the shape function for the distribution of the photons around the mean shower axis. This reference showed that, the photon distribution is most probably to be a power law of the form,

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

Where r is the distance from the shower axis, r_M is the Moleire radius, which is is a natural horizontal scale that is caused by multiple scattering, and determines the lateral distribution of the shower, an since the electron's radiation length in the air depends on temperature and pressure, Moliere radius varies along the shower.

3. CONCLUSIONS:

The method of identifying the primary extraterrestrial nuclei by removing shower-photons from the spectra and study the fatness of the tail of no-photons spectrum and the total area under the spectrum give clear behavior directly proportional to the mass number of the primary nucleus. The conclusion is valid, at least, for incidence energy of 10^{15} eV .

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

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العنوان بالعربي: "تمييز العدد الكتلي لنواة عنصر الحدث الأولي بتحليل بيانات أرصاد الانهمار الجسيمي للأشعة الكونية ذات الطاقات فوق العالية وعند طاقة واحد مليون جيجا الكترون فولت ."

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المستخلص:
استخدام اسلوب بسيط وجديد لمعالجة وتحليل بيانات الأرصاد للانهمار الجسيمي للأشعة الكونية ذات الطاقات فوق العالية، حيث يتم محاكاة وانتاج البيانات لكل حدث أولي، من مجموعة من ستة أحداث عالية الاحتمالية في الحدوث، على الحاسب الالكتروني بطريقة مونت-كارلو وباستخدام نماذج فيزيائية في مجال الفيزياء النووية وفيزياء الطاقات العالية, ثم يتم الحصول على أطياف الطاقة الكلية وكذلك بدون فوتونات جاما لكل حدث. وتم استنباط علاقة مطردة الزيادة بين العدد الكتلي للحدث الأولي والعدد النسبي للجسيمات المتضمنة في الانهمار الجسيمي للأشعة الكونية وهو ما يؤدي الى تقدير أدق للعدد الكتلي لنواة الحدث الأولي.