

Method for the primary mass composition study of ultra-high-energy cosmic rays with the Telescope Array surface detector

G.I. RUBTSOV¹, S.V. TROITSKY¹, D. IVANOV², B. STOKES², G. THOMSON², I.I. TKACHEV¹ FOR THE TELESCOPE ARRAY COLLABORATION

¹*Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, 117312, Russia*

²*University of Utah, High Energy Astrophysics Institute, Salt Lake City, Utah, USA*

grisha@ms2.inr.ac.ru

Abstract: The Telescope Array (TA) surface detector (SD) stations record the temporal development of the signal from the extensive air shower front which carries information about the type of the primary particle. We develop methods for studies of the primary mass composition of ultra-high-energy cosmic rays with the TA SD data and report preliminary results of these studies.

Keywords: ultra-high energy cosmic ray composition, Telescope Array surface detector

1 Introduction

The Telescope Array (TA) experiment [1, 2] is a hybrid detector operating in Utah, USA. The TA consists of a surface detector array of 507 plastic scintillators with 1.2 km spacing covering 700 km² area and three fluorescence detectors. This *Poster* presents a new technique for the primary mass composition study of ultra-high-energy cosmic rays (UHE-CR) based on the time-resolved data from surface detector. The sensitivity of the method for energies higher than 10¹⁹ eV is confirmed with Monte-Carlo modeling.

Primary mass composition is one of the main research targets for large scale extensive air shower detectors. The highest accuracy is achieved in X_{max} measurements with air fluorescence detectors such as HiRes, Pierre Auger and TA [3, 4, 5]. The results of different experiments lead to different interpretations - HiRes and TA data are compatible with pure proton composition, while Pierre Auger Observatory suggests a transition to heavier elements at high energies. The primary mass composition play a primary role in the identification of cosmic ray sources [6, 7] and interpretation of the observed cut-off of the spectrum [8, 9, 10, 11, 12].

The surface detector is capable of measuring chemical composition independently of the fluorescence telescopes. Moreover, the SD provides more statistics at the puzzling highest energy range due to its 95% duty cycle. One of the SD techniques is based on independent measurement of muon component. The Yakutsk array has shown that the muon density for $E > 10^{19}$ eV showers is a factor 1.5 higher than the SIBYLL 2.1 [13] model prediction for iron primaries and may be interpreted using EPOS model [14] as mixed proton and iron composition [15]. Yakutsk muon data suggest that the composition become heavier at energies $E \gtrsim 10^{19}$ eV [16]. Pierre Auger uses two observables for composition study with SD: asymmetry of signal risetime and muon production depth profile [17]. Both agree with the composition becoming heavier at the highest energies. Note, that the mass sensitivity of all of the listed SD observables is determined by their sensitivity to the muon component of the shower. One may not neglect the muon component for SD composition study as the electron-photon shower component is much less sensitive to primary particle type

and shower depth due to the universality of electromagnetic shower [18, 19].

2 Method

Each of 507 TA surface detectors records time-resolved signals with a time step of 20 ns. For each detector we define Area-over-Peak (AoP) as the ratio of the integral of the FADC trace to its peak value. The AoP therefore is measured in time units (ns). The muons arrive close in time to the shower front making AoP smaller, while electron-photon cascade shift AoP towards larger values. The AoP observable was previously introduced by Pierre Auger collaboration for neutrino identification [20]. We fit AoP as a linear function of the core distance and determine the fit value at 1200 m (AoP_{1200}).

We use CORSIKA [23] with QGSJET II [24] to generate hadronic showers induced by primary protons and iron. The showers are simulated with thinning and the dethinning procedure is adopted [25] to simulate realistic shower fluctuations. The detector response is accounted for by using look-up tables generated by GEANT4 [26] simulations. Real-time array status and detector calibration information are used for each Monte Carlo (MC) simulated event. The Monte-Carlo events are produced in the same format as real events and analysis procedures are applied in the same way to both [27].

The statistical method is used to test allowed mass mixtures for each logarithmic energy bin [21, 22].

3 Results

The results of Monte-Carlo simulations will be shown at the conference including histograms for AoP_{1200} for proton and iron primaries. Sensitivity of the method will be presented.

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