Chapter 8

Summary & Future Perspectives

Cosmic rays consist of hadrons, nuclei, photon, neutrino and very small amount of stable anti-particles, originating in outer astrophysical sources. They are highly energetic $\sim 10^6 \text{eV}$ to $10^{20} \text{eV}$, travel at nearly the speed of light and strike the Earth from all directions. Due to low flux, cosmic rays above $10^{15} \text{eV}$ can be studied indirectly by the shower of secondary particles (EAS) they produce in the atmosphere. Different types of ground based detectors or detector arrays are used to measure relevant EAS observables. Derivation of characteristics of the primary CR particle requires input from Monte-Carlo EAS simulations based on H.E. models. For reliable estimation of these properties consistency among the different model predictions is a must. CORSIKA (COsmic Ray SImulations for KASCADE) developed to perform simulations for the KASCADE experiment at Karlsruhe in Germany and consistently upgraded since it inception in 1989 is now a widely used EAS simulation program by the scientific community around the Globe. CORSIKA has, in it, seven H.E. interaction models to treat hadronic interactions up to energies of some $10^{20} \text{eV}$.

Proton-air cross section in the energy range $10^3-10^{11} \text{GeV}$ calculated from the CORSIKA-6990 simulation shows that, up to the 'knee' energies ($3 \times 10^6 \text{GeV}$) all the models agree to within about 6%. At $10^8 \text{GeV}$ agreement is within about 9%. Whereas at $10^{10} \text{GeV}$ SIBYLL and DPMJET agree to within about 20%. The models namely EPOS, QGSJET, QGSJET-II, and NEXUS exhibit agreement within 8% throughout the energy range considered. This clearly indicates that the H.E. models are consistent to produce reliable description of p-air collisions in H.E. and U.H.E. reign.

Here, different statistical parameters of $X_{\text{max}}$ are tested for possible model dependence. The mean depth of the shower maximum, $<X_{\text{max}}>$ as well as the shower-to-shower fluctuations $\sigma_{X_{\text{max}}}$, the relative fluctuations in $X_{\text{max}}$, skewness & kurtosis of $X_{\text{max}}$ distributions

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are found to be more sensitive to the composition rather than H.E. models. Although different H.E. models are based on different physics concepts and phenomenologies, maximum differences in mean $X_{\text{max}}$ values due to the models at $10^{19}$ eV primary energy are 39.7 g/cm$^2$ for proton, and 27.8 g/cm$^2$ for iron.

Study on lateral development reveals that, for muons spread to larger distance from the core compared to electrons. Muons are found to suffer much less fluctuations compared to electron component. Muon charge ratio increases from unity and saturates after a core distance of about 200m. A comparison of the energy spectra of muons above 100GeV shows no differences for QGSJET-II and EPOS-1.99.

The shower size distribution and distribution of total muon number for different primary energies are studied using and statistical parameters namely mean, standard deviation, skewness, kurtosis for different models. Standard deviations (s.d.) and the ratio of s.d. to mean for both the shower size distribution and the muon size distribution are found to be sensitive to primary composition. Assuming QGSJET as the base model, Z-test for all the models are performed. It is found that, muon size distribution shows greater sensitivity for model discrimination, compared to electron size distribution.

At higher energy ($10^8$-$10^{10}$ GeV) Comparison of EPOS-1.99 and QGSJET-II-3 are made using CORSIKA-6990 with a number of EAS parameters. Significant difference between the two models is observed for $X_{\text{max}}$ distribution and truncated muon number (measured between 40m-200m core distance) distribution. Distribution of total electron number, hadrons above 100GeV, hadron energy sum and hadron energy spectra show no significant model dependence.

8.1 The future prospect of this work

There are a number of high energy interaction models used in CORSIKA simulation for Cosmic Ray Air shower study. The choice of the model for interpretation of experimental data, or for comparison of simulation results for different primary energy & mass composition plays a crucial role in correct interpretation of the processes involved. Attempt is made to analyse the effect of various models on the EAS parameters. This work may be extended for shower age related analysis and for inclined showers for better understanding regarding longitudinal shower development. Statistical multi-parametric analysis using new methods & comparison of parameterized fit values are expected to provide reliable results in respect of various measurable components of EAS. More study on muons’ energy spectra for model dependence is possible.