Chapter 8

Discussion

One of the main goals of the present work is to estimate the primary mass composition of CRs in the range from about 0.1 PeV to nearly 100 PeV. This is considered to be a key information for the validation of any CR origin model. From this, a major issue about the existence of a *knee* in the primary CR energy spectrum has to be resolved. A concrete knowledge about the CR mass composition in this region allows us to infer about the origin of galactic or extragalactic CRs. Hence, the over-steepened structure that appears in the spectrum of primary CRs at around 3–4 PeV could be understood. If the observed *knee* structure is linked with issues like CR mass composition, or acceleration and propagation effects, a very systematic variations in nuclear mass composition in the concerned energy region is more likely to evince. But, alternative issues like limited knowledge in the hadronic interaction mechanisms and their effects to the EAS development at these energies, are also very crucial. It is noteworthy to mention that a very stable EAS experiment with a very well unfolding technique would provide high quality data to suffice the issue related to the *knee*. But due to the influence of the hadronic interaction models and the sources of systematic uncertainties, there are disparities in conclusion from experiment to experiment on long existing questions of primary CRs. In this context, the present work prefers to consider several EAS observables in a multi-observable approach employing some new data analysis techniques for the estimation of CR mass composition.

In this thesis the results of the investigations of some relatively new CR composition sensitive air shower observables resulting from different characteristics

of EASs initiated by primary CR particles around the *knee* region has been presented.

From the analysis of simulated EAS events generated with the MC code CORSIKA, we have critically studied the characteristics of lateral distribution of electrons in EAS around the *knee* energy region of the energy spectrum of PCRs. The slope of the lateral distribution of electrons behaves as an indicator of shower age. The shower age parameter is not only describing the stage of development of showers in the atmosphere but it also exhibits sensitivity to the nature of EAS initiating primaries. The correlation of this parameter with other EAS observables is therefore examined, with a view to obtaining information about the CR mass composition from NBU and KASCADE data. It is shown that the observed slope of the lateral density function in the 3-dimensional plot, at least for the KASCADE data, supports the idea of a transition from light to heavy mass composition around the *knee*.

Some potential EAS observables are extracted from the characteristics of lateral distributions of electrons and muons of simulated EASs in the energy regime of the KASCADE experiment, and their CR mass-sensitivity has been demonstrated. This alternative analysis has taken up mean experimental lateral density profiles of EAS electrons and muons from published works of the KASCADE experiment after introducing the notion of the local age and segmented slope parameters, aimed to extract information on CR mass composition from observed data. The estimated lateral shower age from the analysis of the KASCADE data agrees with the idea of a gradual change of CR mass composition from light to heavy around the *knee*.

It is known that the LDD of shower particles from an EAS experiment is commonly approximated by a particular type of LDF. A standard perception is being used in air shower physics since long, according to which the LDD is assumed to be symmetric about the EAS axis, and the adopted LDF is adequate for the description of the LDD. However, the simulated electron density of a non-vertical EAS is asymmetric. We have shown that such asymmetry in the LDD can be qualitatively explained as the atmospheric attenuation suffered by each shower

particle. Quantitatively, the asymmetry can be roughly described in terms of a gap length between the EAS core and the center of the modified density pattern consisting of several equi-density ellipses. This study also validates the use of such a modeling of the atmospheric attenuation on the electromagnetic component in an EAS by investigating the so called gap length in simulated density data. A modified LDF is proposed, based on these features of the simulated densities for the purpose of shower reconstruction in EAS experiments. The gap length arises from attenuation effect is found to increase with the mass of the shower initiating particle. A different radial dependence of the local age parameter is seen, if the modified LDF is applied to simulated electron densities. Primary cosmic-ray mass sensitivity of the local age parameter is also re-examined.

The observation of an EAS also offers to measure the energy of CRs based on the lateral distribution of its secondary particles. Here, we propose quite a few air shower observables for reconstructing the mass and energy of the primary particles. Simulated showers have been generated using the MC code CORSIKA at the KASCADE and NBU levels. Some of the observables obtained from the analysis of simulated data have been used to infer the nature of the primary particles via comparisons to KASCADE and/or NBU data. It is expected that the determination of primary energy of a CR shower may deliver a better accuracy compared to standalone analysis using shower size or S600 or S500 or N_{pe} etc, owing to strong fluctuations in the EAS development.

The effect of the geomagnetic Lorentz force on the muon component of EAS has been studied in a MC generated simulated data sample. This geomagnetic field affects the paths of muons in an EAS, causing a local contrast or polar asymmetry in the abundance of positive and negative muons about the shower axis. The asymmetry can be approximately expressed as a function of transverse separation between the positive and negative muons barycentric positions in the EAS through opposite quadrants across the shower core in the shower front plane. In this study, it is found that the transverse muon barycenter separation and its maximum value obtained from the polar variation of the parameter are higher for iron primaries than protons for highly inclined showers. Hence, in principle, these parameters can be exploited to the measurement of primary CR mass composition.

Possibility of practical realization of the proposed method in a real experiment is also discussed. Furthermore, we noticed that the present analysis has also been found capable of estimating unknown geomagnetic field components of a location. This work has also indicated a possible correlation between any transient change/weakening of the earth's magnetic field due to solar/other activity and corresponding asymmetries in μ^+ and μ^- distributions of a CR induced EAS.

Before wind up this thesis let us refer to an enduring statement of **Victor Franz Hess** in his Nobel Lecture, on December 12th, 1936:

"*From a consideration of the immense volume of newly discovered facts in the field of physics, especially atomic physics, in recent years it might well appear to the layman that the main problems were already solved and that only more detailed work was necessary.*
This is far from the truth, as will be shown by one of the biggest and most important newly opened fields of research, with which I am closely associated, that of cosmic rays."