CHAPTER-I

INTRODUCTION

The cosmic ray work at North Bengal University commenced in 1970, with experiments on unassociated and singly appearing muon component at ground and underground using narrow angle cosmic ray telescope and a large volume multiplate cloud chamber. This type of work continued up to 1973. Since 1979 the interest has widened to include observation of extensive air showers by using an array of electron detectors and two magnetic spectrograph units at a site on North Bengal University Campus. In what follows, attention will be given to the cosmic rays in the energy range below 10^{12}eV which appear mostly as single muons and to the primary cosmic rays of energy above 10^{13}eV which appear as a superposition of successive cascades of a variety of charged particles.

1.1 Cosmic rays at ground level : Single particles

The singly appearing charged cosmic rays at ground level are the progeny of primary nuclei of energy up to 10^{12}eV. The associated soft cascades get absorbed before reaching sufficient depth in the atmosphere. Consequently, the primary energy range up to 10^{12} - 10^{13}eV has been investigated in many experiments indirectly by the study of single muons which could reach down to the ground level and some depth of underground. The cumulative effect of these experiments has been very important in verifying theories on electromagnetic particle interaction at ultra high energy and also in obtaining the information on primary cosmic ray nuclei.

1.1.1 High energy muon interaction processes

The important high energy interaction processes are : direct muon-electron knock on collision process, bremsstrahlung process of muon in the coulomb field of atomic nuclei and direct production of a pair of electron-positron (DPP) by muons in the coulomb field of atomic nuclei and electrons. The muon DPP process is one of the topics of investigation (carried out up to 1978) included in the thesis. The present state of the theory of DPP process has attained an improvement better than the experiments so far reported for this process. In the latest theoretical development, derivation of cross section expressions have been made with high mathematical rigour. Bhabha's[1] (1935) theory of DPP process and similar other treatments were given more than 50 years ago. Bhabha's theory and also theory of Racah[2] (1937) have been used extensively in the past. Except in one case of a theoretical review together with an experimental investigation by Wright[3] (1975), the recent exact calculations (Kel'ner[4], Kel'ner-Kotov[5], Kokoulin-Petrukhin[6] (KP)) have not been used in previous experiments. It appears desirable to make a critical evaluation of old and new DPP calculations in order to understand the degree of improvement attained at present and to know inter-relation among various treatments. Probably there is also a need for critical reanalysis of past experiments on DPP process in view of new theoretical results and more precise data on muon spectra both at sea level and underground. Such an analysis of the existing experimental data may help evaluate the reliability of available theoretical cross sections.

1.1.2 Inter-relation between the atmospheric cosmic rays and the primary nuclei (The galactic cosmic rays)

The inter-relation between the characteristic of primary cosmic ray nuclei, the interaction with atmospheric matter and the secondary components in the atmosphere and underground has been an interesting subject of study. Several analyses on this topic have been available recently. We do not discuss here the details of this treatments by several workers, but only mention that the results of this analysis do not agree on several points.

The measurements of secondary gamma rays at the top of the atmosphere and cosmic rays muons at ground level and underground have been analysed through the nuclear physics of collisions of the primaries with atmospheric nuclei to derive information on primary particles. For this analysis the recent accelerater data on cross sections for single charged pions and kaon production in the inclusive reactions in the proton - proton collisions at laboratory energy up to 1.5 TeV have been used in the work at NBU (done in 1977-78).

1.2 Extensive air showers

The development of an extensive air shower by a primary nucleus of energy above 10^{13}eV in a sequence of successive cascades of a varity of particles results in superposition of these cascades. A high energy primary nucleus, say a proton of energy 10^{14}eV arriving at the top of the atmosphere, collides with a nucleon of air nucleus and loses a fraction of its energy and moves further down in the atmosphere. The energy lost by the primary particle is used for the production of a large number of secondary particles such as pions, kaons, strange particles, nucleons and antinucleons. The neutral pions decay into gamma ray photons which develop electromagnetic cascade showers in the atmosphere. Some of the charged pions and kaons decay into muons which form the main charged penetrating component of an air shower. The remaining pions and kaons and all other hadrons suffer successive nuclear collisions and produce more secondary particles. The surviving primary particle suffers successive collisions and produces hadron cascades. The process of generation of hadronic and electromagnetic cascades continues deep down in the atmosphere resulting in the superposition of all these cascades containing a large number of secondary particles which spread out laterally over large distance from the axis of the shower due to large separation between successive interactions. In the longitudinal development both hadronic and electromagnetic cascades reach their maximum at different depths in the atmosphere depending on the energy of the primary particles and the characteristics of hadron-hadron collisions. The particles of an air shower arrive in the form of thin disc of few metres thickness at the level of observation at mountain altitude and at sea level. The various components of the disc are the following :

i) the soft component (electrons, positrons and photons).

ii) penetrating component (muons)

iii) hadronic component (pions, kaons and other hadrons)

iv) Carenkov light

v) Radio waves

vi) Atmospheric fluorescent emission in air showers. Many experiments have been performed on the air shower components and the cumulative effect of all these have contributed to the understanding of various (1) astrophysical aspects of cosmic rays (2) the characteristics of ultra-high energy nuclear interactions and (3) to a search for narrow angle directional anisotropy at the highest energy range 10^{15} to 10^{20}eV of cosmic charged and gamma radiation.

We will briefly mention here the various aspects of charged electromagnetic component (mostly electrons and muons) which has been the subject of investigation at the North Bengal University.

1.2.1 The soft component

The total number of electrons in an air shower is determined to estimate the initial energy of the primary particles through the relation $N_e \propto E^{\beta}$, where E is the primary energy and $\beta = 1.15$ for $N_e < 5 \times 10^5$ (De Beer et al[7]). The shower size N_e is obtained from observed electron lateral distribution measured by sampling the electron densities at a number of points in the shower front and fitting these data to determine the shower core-co-ordinates and shower age. For this purpose the distribution function given by Nishimura-Kamata-Greisen[8,9] (NKG) has been used extensively by experimenters. Recent measurements[10-20] of electron lateral distribution near sea level in various shower size groups have indicated that the NKG function does not fit well with the measured electron densities as a function of distance from the shower axis in individual showers in small shower size groups.

New forms of lateral distribution function [Hillas et al[21], Lagutin et al[22], Kaneko et al[13], Capdevielle et al[23], Dedenko et al[11], Hara et al[24], Linsley[25]] have not yet been fully tested using two or more structure functions.

1.2.2 The muon component

The muon component in air showers has been studied to derive information on the composition of primary cosmic rays. This is due to the dependence of total number of muons in the showers to the charge-number of primary particles. Some recent experiments[26-28] have reported detection of air showers with fewer muons as a support of photon primaries whereas Kiel group[28] detected high energy γ initiated air showers with total muon number nearly the same as in proton or nucleus initiated showers. The longitudinal development of nuclear cascades in air showers has been studied using the muon component. The lateral distribution of muons has also been studied to obtain information on the characteristics of high energy interaction. The situation about muon data together with the different interaction model calculations is not yet conclusive. The new experiments by various groups [Akeno group[29], Moscow group[30], Tata group[31], Tien Shan group[32], Yakutsa group[33], Miyake et al[34], Gibson et al[35], Kiel group[36], Reda et al[37]] are in progress for studies of different aspect of muon component.

1.3 Present work

As already mentioned, the cosmic ray work at North Bengal University was started by setting up a large multiplate cloud chamber for the study of interaction of muons with matter. The work was continued until the new air shower project was started by the Department of Atomic Energy, Govt. of India. The part of the work on muon interactions carried out by the candidate is presented in the chapters II and III.

An installation of a new apparatus for observation of air showers was then established near sea level at North Bengal University Campus. The apparatus consists of an array of sixteen density sampling detecters, neon-flash-tube muon detector and two magnetic spectrograph units as muon detector. The electronics for the instrumentation and control was designed and fabricated and applied for some air shower measurements by the author and his coworkers. The detailed description of the design and electronics has been presented in the thesis (Chapter IV and V). The measurements on electron and muon lateral distribution in showers at sea level of size group 10^4-10^6 have been carried out. The results are presented in the thesis (Chapter VII).

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