CHAPTER II

A SUMMARY OF RECENT MEASUREMENTS OF EAS ELECTRONS AND MUONS

2.1 Introduction

The study of EAS is very complicated since most of the observed parameters are dependent on high energy interaction characteristics and primary particles both of which are unknown. The development of EAS depends on the interaction cross section, multiplicity of various kinds of secondary particles and its direction, the average value of inelasticity and energy dependence of all parameters. So the information on both characteristics of high energy interactions and primary composition has to be inferred from EAS studies. Various results regarding primary particles have been summarised by various authors[1-3] from recent EAS measurements.

In the analysis of a shower, size, age and core position are determined by density sampling and fitting with the standard distribution functions. The energy and the lateral distributions of muons and the total number of muons (N_μ) in a shower are obtained for different threshold energies by direct measurements.

2.2 Distribution of electrons in EAS

According to the cascade theory for a pure electro-magnetic shower, the density of electrons at a distance, r from the core of a shower is written as,

$$\Delta(N_e, s, r) = [N_e \cdot f(r/r_o, s)] / r_o^2 \quad m^{-2}$$

where N_e is the total number of electrons (shower size), r_o is known as Moliere scattering length, s is the age of the shower, a measure of the longitudinal development of the shower.

The longitudinal and the lateral development of the electron-photon cascade initiated by a photon or an electron has been carried out theoretically by different authors[4,5] and discussed exhaustively by Nishimura and Kamata[6]. Based on these results of electron lateral distribution of cosmic ray air showers, a semi-emperical relation for the showers of maximum development and for showers of age upto 1.4 has been given by Greisen[7] as

$$\Delta(N_e, s, r) = C(s)N_e(r/r_o)^{s-2}\,(1 + r/r_o)^{s-4.5} \quad m^{-2}$$

where C(s) is normalising constant and the expression of C(s) used for actual evaluation are as follows

$$C(s) = 0.443s^2(1.90 - s) \text{ for } s < 1.6$$
$$= 0.366s^2(2.07 - s)^{5/4} \text{ for } s < 1.8$$

In recent measurements[8-18] of electron lateral distribution, it has been shown that NKG function is not a good fit to the densities as a function of r. The possible errors introduced in the estimation of size and age parameter due to use of NKG function in fitting the lateral distribution is discussed in great detail by Capdeville et al[19, 20] and it has been pointed out that it is very difficult to describe the observed lateral distribution of electrons in EAS with a single age parameter. The formula of density distribution of electron is as follows

$$\Delta(N_e, r, s) = [N_e/m^2 r_o^2] \, C_{HG}(s) \, [r/mr_o]^{s-2} \, [r/mr_o + 1]^{s-4} \, [1 + d.r/mr_o]^{2.5-s} \quad m^{-2}$$

where d = 0.026, m = 0.5 and

$C_{HG}(s) = 0.3265 \exp[-0.5(s - 1.125)^2/(0.499)^2]$ for $s \leq 1.4$

and $C_{HG}(s) = 0.2854s^2 - 1.385s + 1.66$ for $s > 1.4$

Hillas and Lapikens[21] have simulated electron initiated cascade showers in the atmosphere and have developed a lateral distribution function taking into account various energy dependence of electron and photon interaction processes down to an energy less than 1 MeV. This is the most detailed simulation of cascades by electron and photon primaries upto 100 GeV. The lateral distribution of electron is represented by the following relation

$$\Delta(N_e, r, s) = N_e C(s) \, [r/r_o]^{a_1 + a_2(s-1)} \, [1 + r/r_o]^{b_1 + b_2(s-1)}$$

where C(s) is the normalisation constant and the parameters, for the range s = 0.6 to s = 1.5, are chosen for the best fit of the experimental results as r_o = 24 m, a_1 = -0.53, a_2 = 1.54, b_1 = -3.39 and b_2 = 0.

New forms of lateral distribution function presented by different authors [Hara et al[22], Linsley[23], Dedenko et al[9], Kaneko et al[11], Lagutin et al[24]] have not yet been fully tested.

2.3 Distribution of muons in EAS

Muons in EAS carry information about the longitudinal development of an air shower at different depths of the atmosphere. In EAS not more than 10% of the total particles are muons which spread out to wider area than electrons. The size of an air shower depends strongly on the total energy of the primary while the total number of muons in a shower depends upon the energy per nucleon of the initiating primary. The lateral distribution of muons depends on high energy hadron interaction characteristics.

The muon energy spectrum and the lateral distribution of muons have been studied by different authors[25-33]. In 1960, Greisen[7] compiled the results of Bennet, Clark, Earl, Kraushaar, Linsley, Rossi and Scherb and give the expressions of energy dependence and size dependence of muon distribution and size dependence of muon energy spectrum. He has given an emperical relation of muon distribution for muon energies upto 500 GeV and the shower size range 10^5-10^8 as

$$\rho_\mu(>E_\mu, N_e, r) = \frac{14.4\ r^{-0.75}}{(1+r/320)^{2.5}} \left[\frac{N_e}{10^6}\right]^{0.75} \left[\frac{51}{E_\mu+50}\right] \left[\frac{3}{E_\mu+2}\right]^{0.14r^{0.37}}$$

$$N_\mu(>E_\mu, r) = 1.7 \times 10^5 \left[2/(E_\mu+2)\right]^{1.37} \left[N_e/10^6\right]^{0.75}$$

where ρ_μ is the density of muon with energy $>E_\mu$ and at a distance r from the shower core. N_μ is the total number of muons per shower.

The integral energy spectrum of muons in a shower of given size could be represented by a power law with an exponent in the range of -1.2 to -1.6 at muon energies >100 GeV by several authors[34-37]. Below this energy the spectrum flattens continuously and the exponent is about -1.0[35-38].

Khrenov and Linsley[39] have deduced an emperical formula by using the recent data from Moscow Magnetic spectrometre as follows.

$$\rho_\mu(>E_\mu, N_e, r) = \frac{5.10^3}{(E_\mu+250)^{1.4}} r^{-0.55\eta^{0.1}\psi^{0.07}} \exp(-\eta^{0.62}.r/80)\psi^{0.78}\ m^{-2}$$

$$N_\mu(>E_\mu, N_e, r) = 2 \times 10^5 (E_\mu+250)^{-0.65}\, \eta^{-1.25}\, \psi^{0.78}$$

where $\eta = (E_{\mu} + 2)/12$ and $\psi = N_e/2.10^5$, valid for the shower size range $3.10^4 - 10^6$ and muon energy range 5 GeV to 6.10^3 GeV.

Lateral distribution of muons with threshold energies less than 500 GeV has been studied by several authors(13,28,40-44). Both power law and exponential forms have been used to fit the data. The density of muons at a distance r from the axis of the shower is

$$\rho_{\mu}(r) = Ar^{-\alpha}\exp(-r/r_o) \qquad m^{-2}$$

By integrating this equation over whole area, the total number of muons has been found. By using the relation of shower size and muon size, many authors(26,41,45-51) have attempted to extract the information on high energy interactions as well as compositions. The age dependence of lateral density distribution of low energy muons have been studied by several authors(40,41,52). They have shown that the densities are larger for older shower than the younger ones.

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